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Oil geology of the
Titusville quadrangle

COMMONWEALTH OF PENNSYLVANIA
DEPARTMENT OF INTERNAL AFFAIRS

OIL GEOLOGY
OF THE
TITUSVILLE QUADRANGLE
PENNSYLVANIA

By
PARKE A. DICKEY

TOPOGRAPHIC AND GEOLOGIC SURVEY
BULLETIN M 22
1941

PENNSYLVANIA
GEOLOGICAL SURVEY

FOURTH SERIES

BULLETIN M 22

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PARKE A. DICKEY

DEPARTMENT OF INTERNAL AFFAIRS
William S. Livengood, Jr., *Secretary*

TOPOGRAPHIC AND GEOLOGIC SURVEY
George H. Ashley, *State Geologist*

Harrisburg, Pa.
1941

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FOREWORD

This bulletin has an interest far beyond the small area it describes, or the people who are financially interested in its oil deposits. "Firsts" are commonplace in Pennsylvania. She is 32d among the States of the Union in size but first in a hundred ways. Only ninth among the States in her coal deposits, until about 1920 she had produced more coal than all the other States combined. Today she is eleventh in the production of oil, but for years she was the only State producing oil commercially and she led in the production of oil for 35 years, taking second place in 1895. Her total output of oil in 80 years is exceeded by only four States, all comparatively newcomers in the industry.

Today Pennsylvania would hardly be more than a memory in the oil industry were it not for secondary methods in oil recovery, in which she has led, just as she did in the original recovery of oil. A year or more ago it occurred to the oil-scouts of some of the large producers of the Southwest, where oil occurs at great depths, that Pennsylvania, West Virginia, and Ohio, whose wells are shallow, might also contain large quantities of oil at great depths. Accordingly, they began a trek to the east by the score, ready to drill to 10,000 feet or more. Instead they discovered that oil does not occur deeper than 3,000 feet in Pennsylvania. This comparatively shallow depth is in accord with David White's oil-coal formula when allowance is made for increasing fixed carbon in coal with depth. The Pennsylvania industry would tell these oil-scouts, as the tombstone put it, "As you are now, so once was I; as I am now, so you will be," in this instance not dead, but kept alive only by complete knowledge and the highest skill.

Today, as 80 years ago, the oil men of Pennsylvania are ahead of the pack in devising new ways of meeting new conditions. When the oil sands were first drilled into, the oil flowed into wells because of the gas dissolved in the oil or trapped above the oil in the sand. As the oil was withdrawn the gas escaped too, but faster than the oil. Eventually, the oil would no longer flow into the wells because gas pressure was gone. Large quantities of oil remained in the rock, in some instances six or seven times as much as had been withdrawn. How to recover that oil short of mining the rock and distilling the oil out has been the problem of the Pennsylvania industry. The use of water under high pressure through intake wells has long been practiced in the Bradford field. This method has not been successful in other fields in Pennsylvania, though it may be in some fields not yet tested.

In the area discussed in this bulletin air and gas have been used with success in place of water. But many problems are encountered. The oil sands are not uniform in permeability. Air and gas under pressure pass readily through the more permeable layers and by-pass the denser layers, where most of the oil still remains. How to induce the oil to leave the denser layers is a first problem, but only one.

Unlike most of the oil deposits of the Southwest, those of Pennsylvania are only slightly related to structure. As developed in this paper, relations to old shore lines, to thickness of beds, and other conditions existing when the oil-bearing sandstones were laid down may play a much more important role than structure.

A third problem is to forecast the quantity of oil in a pool that has already had its day. Secondary methods of recovery are expensive. It is most desirable to know in advance that there is enough oil in a given pool in a given sand to warrant the high cost of its recovery. These are some of the matters dealt with in this report. Furthermore, it deals with the oldest oil field in the world, and, therefore, one which, because of the large amount of information available, is of peculiar interest. It is believed that the matters discussed in this bulletin and the solutions offered will be of interest to oil men everywhere.

Geo. H. Ashley

OIL GEOLOGY OF THE TITUSVILLE QUADRANGLE, PENNSYLVANIA

By Parke A. Dickey

INTRODUCTION

Location and Culture

The Titusville quadrangle is in northwestern Pennsylvania and occupies parts of Warren, Crawford, Venango, and Forest Counties. It covers about 220 square miles, of which about 67 square miles are producing oil fields.

The city of Titusville in the southeast corner of Crawford County is near the middle of the quadrangle. It has a population of about 8,000 persons. The principal industries are oil refining, and the manufacture of heavy forgings and internal combustion engines. The city is served by the Pennsylvania and New York Central railroads

Pleasantville, near the northeast corner of Venango County, has a population of about 600 persons, most of whom are dependent on the production of oil for a livelihood. Hydetown and Grand Valley are smaller boroughs dependent on agriculture and oil production.

The western half of the quadrangle exhibits a gently rolling topography, and is occupied by many prosperous farms, principally devoted to dairy cattle. The eastern part of the quadrangle is largely woodland. Most of it has been repeatedly cut over and there is no large timber. When the first settlers came in the early part of the 19th century there were splendid stands of pine; huge rotting stumps and logs may still be seen in the woods. At present hemlock is fairly abundant, and oak, ash, and maple sustain several sawmills in the district. The most important industry is crude oil production.

Purpose and Method of Investigation

The mapping of this quadrangle is part of a program of detailed investigation of the old Middle Venango oil fields. The Tidioute and Hilliards quadrangles have already been mapped and preliminary reports published. Field work on the Franklin and Oil City quadrangles has been completed and a report on the Franklin quadrangle is in preparation. A comprehensive report on the entire district is being prepared.

The Middle Venango fields are the birthplace of the modern petroleum industry. Production has been small since flush production ceased and interest shifted to newer and more prolific pools. Much of the original oil still remains in the sands, however, and the development of secondary methods of oil recovery has revived interest in the district and the hope that it will be possible to recover a large amount of the remaining oil. A thorough knowledge of the geology of the field is a prerequisite to intelligent application of secondary recovery methods, an appraisal of their potentialities, and to the intelligent search for new pools.

It was decided early in the program that the reconnaissance type of geological study such as had been made for the oil fields of southwestern Pennsylvania would not give a sufficiently complete and clear picture of the subsurface geology to serve the purposes of the study. It was, therefore, decided to accumulate all available information. It has not been possible to collect and record everything still available, but this study, like the reports on the Tidioute (1) and Hilliards (2) quadrangles, and the Bradford Oil Field (3), is based on many more field data than usual in studies of this type.

Almost every available well record was collected, a total of about 7,680 in the quadrangle. Of these, 3,370 were located on a map with a scale of four inches to the mile, and their elevation determined. About three-quarters of the well elevations were determined with aneroid barometer (Paulin altimeter), but a large number were determined by plane-table traverses. It was intended that the maximum vertical error should not exceed 5 feet, but some few wells may be as much as 10 feet in error. Of these records about 400 have been selected as reliable and representative and are included in this report. (Table 6.)

The work was done between July 1938 and October 1940, by Parke A. Dickey, assisted during much of this time by E. H. Ashton, W. S. Lytle, and J. H. DeLong, Jr., whose conscientious and intelligent work forms the basis of the report.

Acknowledgments

With almost no exceptions, the oil operators of the district assisted in the work, making their records available to the Geological Survey and helping to locate the wells. It is impossible to list here all those who cooperated. Among those companies who contributed freely of their time we should like to thank particularly:

National Petroleum Co.	Titusville, Pa.
Brundred Oil Co.	Oil City, Pa.
South Penn Oil Co.	Pittsburgh, Pa.
J. P. Eaton Corp.	Grand Valley, Pa.
"D" Oil Co.	Oil City, Pa.
Pitt-United Oil Co.	Titusville, Pa.
W. T. and J. A. Lytle	Pleasantville, Pa.
Clinger Oil and Gas Co.	Tidioute, Pa.
Warner-Caldwell Oil Co.	Titusville, Pa.
E. C. Breene	Oil City, Pa.
Red Valley Oil Co.	Oil City, Pa.
W. E. Fertig	Titusville, Pa.

Many of the operators gave the writer the benefit of their experience with local problems and their ideas on the petroleum geology and technology of the district. In particular, the writer wishes to express his debt to C. C. Hogg and R. B. Bossler for their interest and

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Numbers in parentheses refer to the reports listed on pages 64-65.

sympathy in the work, and to point out that many of the ideas here expressed are theirs. Other members of the Geological Survey have assisted in the work, especially Drs. R. E. Sherrill and C. R. Fettke, and L. S. Matteson. The writer's particular thanks are due to Dr. R. W. Stone for his critical reading of the manuscript and many helpful suggestions. Mrs. Janet W. Dickey prepared the samples for heavy mineral analysis.

GEOGRAPHY

Relief

The Titusville quadrangle lies within the geographic division known as Allegheny High Plateaus of the Appalachian Plateaus Province.

Many of the hills are rather flat-topped and mark what was clearly an old erosion surface which has been uplifted and dissected. This surface rises from about 1,600 feet in the southern part of the quadrangle to 1,700 feet in the northern part. The valley of Oil Creek rises from 1,050 feet on the south boundary of the quadrangle to 1,230 on the west boundary.

Drainage

The quadrangle is in the Allegheny River drainage basin, the river lying a few miles outside of and parallel to the southern and eastern margins of the quadrangle. The greater part of the area is drained by Oil Creek and its tributaries. The southeast quarter of the quadrangle is drained by Pithole Creek and Stewart Run, which empty directly into the Allegheny River.

Glaciation

The quadrangle lies near the southern limits of two of the encroachments of the North American ice sheet.

Illinoian moraine. No characteristic moraine of the Illinoian stage has been recognized within the quadrangle. Several gravel banks on high divides can hardly be accounted for by the Wisconsin ice, notably one south of Jerusalem Corners, and they are believed to be remnants of the Illinoian glaciation.

Wisconsin moraine. The terminal moraine of the Wisconsin ice sheet crosses the northwest corner of the quadrangle, passing just northwest of Maple Grove School, Cloverdale Corners, Gilson Ridge School, and Hydetown. No attempt was made to study it or trace it exactly, but it is clearly evident in the topography and is well shown on the topographic map.

Previous to the advance of the Wisconsin ice sheet the drainage of this part of northwestern Pennsylvania was northwesterly towards what is now Lake Erie (4, 5). Oil Creek flowed north instead of south as at present, and its headwaters probably were near Titusville. Caldwell Creek probably also flowed north. During the maximum advance of the ice sheet tongues of ice may have occupied the old preglacial valley of Oil Creek and Pine Creek as far south as Titusville. The ice deepened the valleys and probably also straightened and otherwise modified them.

While the ice sheet occupied the area to the north, it was impossible for the water to flow out in that direction. Furthermore, the melting of vast quantities of ice at the southern edge of the glacier provided abnormally large quantities of water to be disposed of. The upper valleys of the north-flowing streams were thus dammed up, and became short-lived lakes. The waters had to seek exit over the crests of the divides to the south. The large amounts of water quickly cut deep gorges. The valley of Oil Creek below Titusville is an excellent example of such a gorge. The old divide probably was near Boughton, and from there to Oil City the water followed and greatly deepened the channel of an old water course. The small side streams probably at first were unable to deepen their channels as fast as the main bed was deepened, and were left hanging, spilling their waters down over waterfalls. Since the retreat of the ice, most of them have cut back and smoothed out the waterfalls, but one stream on the west side of Oil Creek one mile above Miller Farm is still a hanging valley with waterfalls over hard sandstone ledges.

Evidence of the lake that occupied Oil Creek Valley can be seen in the terraced gravel banks on the hillsides south and east of East Titusville, and the large gravel banks on the main road one mile south of Titusville. The valleys of Oil Creek, north of Titusville, and of Caldwell Creek, were filled with debris, principally gravel, sand, and clay. On Watson Flats, east of Titusville, the rock floor lies about 100 feet below the present valley surface, the original valley being filled to that height with soft clay and gravel.

STRATIGRAPHY

EXPOSED ROCKS

A study of the outcropping rocks in northwestern Pennsylvania was made in 1935 and 1936 by S. H. Cathcart, and his observations in the Titusville quadrangle have been amplified by the author. However, the nomenclature and relations of the exposed rocks of the Titusville quadrangle cannot be entirely clarified until the mapping of other parts of the district is complete. No map showing surface structure is therefore included with this advance report, but will be included in the final report on the area.

PENNSYLVANIAN SYSTEM

Pottsville series. A heavy sandstone, occasionally pebbly, caps a few of the higher hills in the eastern part of the quadrangle. Good exposures of it are rare, and it is usually seen as large, loose blocks and rock cities. The exact position of its base is, therefore, impossible to determine, but it appears to be from 250 to 300 feet above the base of the Corry sandstone. It is not certain whether this sandstone is the equivalent of the Olean conglomerate which is well developed to the northeast, or the Connoquenessing sandstone, which is well developed to the southwest. It is not always well developed and recognizable. At Pleasantville and east of Pithole a thin coal seam is present about 400 feet above the Corry sandstone.

It was pointed out by Butts (25) and has since been substantiated by other work in the district, that the Pottsville rocks lie unconformably on the older beds, which were very gently tilted to the south. The Pottsville series rests on older and older beds towards the north and east.

MISSISSIPPIAN SYSTEM

Shenango group. A series of sandstones and shales with some calcareous sandstone and sandy shale occupies about 120 feet of section below the Pottsville. In the upper part there is a rather persistent sandstone bed, 30 to 40 feet thick, whose top is about 240 feet above the Corry sandstone. It is not well exposed, but was noted in two of the sampled wells. At the base of the series is a widespread and frequently exposed bed of sandstone about 30 feet thick, whose base lies from 130 to 150 feet above the Corry sandstone. It is generally a coarse quartz sandstone, and is noticeably pebbly in the northwest corner of the quadrangle. It usually contains numerous ferruginous concretions and cavities. Well cuttings show that it is usually underlain, either immediately or 10 feet below its base, by a fine calcareous sandstone bed. This sandstone has generally been considered to be the Shenango sandstone by previous workers in the district (1, 7) although it has not been definitely traced to the Shenango in its type area.

Cuyahoga group. From 130 to 150 feet above the Corry are dark gray shales, gray sandy shales, some reddish-brown shales, and fine sandstones comprising the Meadville, Sharpsville and Orangeville formations. The sandstones are frequently calcareous, but do not seem to occupy any constant position, and it was not found possible to divide the group into the subdivisions proposed by I. C. White for the Meadville district (6).

Corry sandstone. The Corry sandstone is the most persistent of the sandstones of this district, and is the only one suitable for use as a key horizon. It is a fine, rather massive, but occasionally platy sandstone, pure white or yellowish white on a fresh surface, and characteristically weathers pasty or chalky white. It is harder and more compact than the other sandstones.

Within the Titusville quadrangle the Corry generally consists of three members. The upper sandstone member is usually the more massive, and is from 8 to 15 feet thick. The middle member is shale with thin sandy shale and platy sandstone beds, and ranges from 5 to 10 feet in thickness. The lower member is fine, hard, platy sandstone, 10 to 15 feet thick. Certain beds are richly fossiliferous and frequently calcareous. The fauna has been described by Kenneth E. Caster (7, p. 123). The Corry sandstone is generally believed to be the equivalent of the upper part of the Berea formation of northern Ohio.

Cussewago formation. The Cussewago formation is well exposed along Oil Creek Valley. It consists of 80 to 100 feet of alternating beds of very fine, light gray, flaggy sandstone, and dark gray shale and sandy shale. A faint reddish color is occasionally noted in the shales. The sandstones are frequently fossiliferous and some contain abundant crinoid fragments. Some beds are quite calcareous.

The Cussewago is probably the equivalent of the Knapp formation of the Bradford area, as pointed out by Caster and others. Caster has subdivided the Cussewago and named the various members from localities near Kane, Bradford, Tidioute, and Meadville. It is very doubtful whether such a general subdivision is either wise or appropriate, for the formation changes character from a coarse conglomeratic series near Bradford to an extremely fine, silty sandstone and shale series in Crawford County. It is not possible to correlate the individual sandstone beds from drill cuttings throughout the Titusville quadrangle. However, electric logs of several wells show that there are three prominent sandstone beds which are widespread in the southern part of the quadrangle. Their tops lie 40, 55, and 75 feet below the base of the Corry sandstone.

A calcareous bed is sometimes, but not always, noticed about 100 to 120 feet below the base of the Corry. In the Dennis Run section it is abundantly fossiliferous, and is called the Marvin Creek zone by Caster. At Riceville a limestone bed 50 feet below the Corry was called Marvin Creek by Caster (7, p. 95). However, it was relocated by the author in the new road cuts 25 feet below the Corry and it is doubtful if it is equivalent to the Marvin Creek. The fact that fossiliferous and calcareous beds are common throughout the Cussewago formation makes the identification and naming of any one of them hazardous. Dennis Run is near Tidioute, Marvin Creek near Smethport, and Riceville is in Bloomfield Township, Crawford County.

SUBSURFACE ROCKS

Strata below the Cussewago formation are not exposed in the quadrangle, but have been penetrated by more than ten thousand oil wells. As a rule the records kept by the drillers are incomplete, but drill cuttings were obtained from five wells in the quadrangle, and electric logs have been secured for several districts, so that complete and accurate information on the subsurface formations is available down to the base of the Venango oil sand group.

DEVONIAN SYSTEM

Riceville shale. Shales with occasional thin silty sandstone beds, 90 to 100 feet thick, extend from 80 to 170 feet below the Corry sandstone. These shales are characteristically reddish, especially in their lower part, and are generally noticed but not recorded by the drillers. The reddish color is noticeable even in weathered outcrops near Tidioute.

Examinations of the outcrops, drill cuttings, and electric logs indicate that this formation is a stratigraphic unit, distinguishable from the sandy Cussewago above and First Sand formation below. It corresponds exactly in thickness and position with the Riceville shale as defined by I. C. White (6, p. 97), although it is not included in his Riceville section.

TABLE 1.

Average position and thickness of shallow oil sands in Titusville Quadrangle.

Age of sands			Customary name of sand	Average interval to Corry	Average thickness	Other names used in area indicated	Tidioute Q. correlations	Approx. proven productive acreage
MISSISSIPPIAN	POCONO		Bluff or Mountain sand	+185	30		Shenango	Fresh water
			Corry, Blue Monday or Mountain sand	0	30		Corry	Fresh water
DEVONIAN	VENANGO OIL SAND GROUP		First sand formation (First sand pay)	—200 —(240)	80 (37)	Amber (SW ¼)	First sand	12,800
		Second sand formation	Red Valley sand	—335	19	Second, Lytle (E ⅓)	Second sand	8,900
			Second sand	—390	21	Salt (E ⅓)	Salt sand	9,600
		Third sand formation	Third Stray sand	—490	16	Third (NE ¼) Black-oil (SE ¼) Gray (SW ¼)	Third sand	24,800
			Third sand	—530	33	Fourth (NE ¼) Green-oil (SE ¼)	Fourth sand	18,600
	CHEMUNG		First Warren sand	—1,000	Shells		First Warren sand	Small shows gas
			Queen sand	—1,170	Shells		Queen sand	Small shows gas
			Speechley sand	—1,420	Shells		Speechley sand	

Caster's suggestion that this member be called the Oswayo shale (7, p. 95) seems unfortunate. The Oswayo of the Bradford district is distinguished from the underlying Cattaraugus principally on the basis of its greenish and gray color, and both Oswayo and Cattaraugus are names of facies. The Riceville shale is very probably the equivalent of the upper part of the Oswayo of the type region, but much more detailed work must be done before the Oswayo-Cattaraugus contact can be identified in the Titusville district. Bright red strata are often associated with the Second Sand formation in the Venango field, and these rocks are undoubtedly equivalent to some part of the Cattaraugus.

There is no evidence in the Titusville quadrangle for a disconformity at the top of the Riceville shale, but Caster's suggestion that it marks the top of the Devonian system seems reasonable, and is accepted for this discussion.

VENANGO OIL SAND SERIES

Below the Riceville shale is a group totalling 330 feet in thickness in which are located the oil-producing sands of the Titusville quadrangle. The name Venango Group of oil sands was first applied definitely to the group by Ashburner (8, p. 12). It was subsequently used by Carll (9) and White (6). Carll in 1875 had recognized the three sandy members of the group (10). The three sandy members have been correlated with sandstones named from their places of outcrop. The First Sand probably is equivalent to the Woodcock sandstone of Crawford County; the Second Sand to the Salamanca sandstone of the Bradford district; and the Third Sand is probably the Panama conglomerate (7, 11, 12). It is preferred, however, for this discussion to use the older and somewhat inelegant drillers' terms, First Sand formation, Second Sand formation, and Third Sand formation.

A detailed subsurface study such as forms the basis of this report is founded on thousands of observations of the geological horizons, and a far more complete picture of the stratigraphy may be obtained than is possible by a study of outcrops. Detailed descriptions of the various sands in the different parts of the quadrangle will be found in the discussions of the oil geology in a subsequent portion of this paper.

The reader is referred to Section I which is based on electric logs and the examination of drill cuttings and cores. It was impossible to secure electric logs of the same wells that were completely sampled, but the exact position of the stratigraphic units is shown by the electric logs, and their character may be determined by examination of samples from near-by wells. The logs shown are self-potential or spontaneous polarization curves, showing high negative electric potential to the left. The electric potential is caused principally by the water in the drill hole filtering into the sands, and maxima, therefore, indicate sandy beds; the height of the maxima being some indication of their permeability. Resistivity logs, whose maxima depend principally on the fluid content of the strata, are not shown.

The five principal sandy members of the Venango series are shown by maps II to VI. These have been compiled from all the well records in the quadrangle. The base maps, in black, show the location of the producing oil fields, and for two of the sands, the elevation of the top of the sand above sea level. Wells whose position and elevation were determined, and whose logs record the sand as present, are shown by black dots.

The colored stippling shows the approximate thickness of the sand as given in the well records. Where wells are not present, the sand thickness has been projected, and other interpretations are of course possible. As a rule, in districts where there are no wells, it is assumed that none of the sands are present.

It is very doubtful if there is a farm in the quadrangle (except in the northwest portion) that does not have at least one abandoned well on it. The very existence of many of these wells has been forgotten, and in very few cases have the records been preserved. The location of many of these abandoned holes was attempted, but in few cases were records or authentic information available concerning their results. The value of this study would have been greatly increased if many of these wells had been located, but it was decided that it would be impossibly difficult to get information sufficiently complete to be of value. It must therefore be assumed that wells may, and probably have been drilled in most of the blank areas on the map. A well that now would be considered a good pumper might have been abandoned as non-commercial during the last century, so that the presence of abandoned wells does not entirely condemn an area. On the other hand, the most profitable leases at present are those that were richly productive when first drilled.

It is doubtful if any important pools remain to be discovered in the Titusville Quadrangle. It is possible that small and isolated bodies of sand may be discovered, especially in the First Sand formation.

The sand thickness maps indicate the "trends" of rich sand more clearly and accurately than production maps. The existence of these trends was noted by the early drillers, and has formed the basis of most prospecting. In some places there are suggestions that the actual thick zone changed its bearing or was offset, while the wells were extended in the direction in which the trend was thought to lie. It is suggested that the thickness maps published in this report will be useful in indicating the best areas for development, especially if they are supplemented by large-scale and detailed thickness maps compiled by the operator for the leases in question.

First Sand formation. What is generally called by the drillers the First Sand formation is a sandy zone 80 to 85 feet in thickness, consisting of beds of shale, sandy shale, and sandstone. The latter are usually fine, but in some places are coarse and even pebbly. When they are sufficiently porous, they contain oil and gas. These porous beds or "pay" sands are as a rule of small area and highly irregular. They may occur anywhere from the top to the bottom of the "formation", but appear to be more extensive and frequent near the bottom.

Occasionally the drillers record correctly the top and bottom of the First Sand formation, but as a rule the top of the first "pay" sand encountered is called the top, and the bottom of the lowest pay, the bottom, even though there may be beds of shale and sandy shale between. In consequence the well records are exceedingly confusing, and adjacent wells often show widely varying sand thicknesses. When no pay beds are encountered, the sand may or may not be recorded. During the early development of the field, the First sand was generally considered to contain "slush oil" and to be worthless. Just what was meant by "slush oil" is not entirely clear, but apparently it was oil that made a good show while drilling, but failed to continue producing. Most of the First sand is relatively impermeable and at a shallow depth, which explains why no very large wells were encountered in it. On Goodwill Hill a very prolific field has been developed, in some parts of which the First sand was not even recorded as present in the logs of the original Third Stray sand wells.

Because of the variable nature of the First sand, it is impossible to draw either structure or thickness maps for it. The First Sand map shows the position of the wells located by this Survey that record

First sand as present. The areas where the First sand is considered productive are enclosed by lines fringed on the side toward the production.

Since it was not possible to correlate individual sand beds in the First Sand formation, it is impossible to present a clear and accurate picture of the shape and character of the sand body, as is done for the lower sands. The general picture is about as follows:

Northwest of a line striking N 32° E and passing through the northwest corner of the borough of Titusville, the First sand is present, but often contains large quantities of water. This water appears usually to be fresh, and its presence may be due to the outcropping of the sand beneath the glacial valleys. The sand is rather fine, but in some of the wells seems to have good porosity and permeability. Southeast of the line the sand is present, but porous only in certain beds in certain localities. These localities are highly irregular in size and shape, and it is difficult to make generalizations concerning them.

In the northeast third of the quadrangle a series of porous sand bodies trends southeast from a point in the center of the northern edge of the quadrangle. The northwestern bodies are smaller, but are coarse and frequently quite pebbly. Farther southeast, in the Goodwill Hill pool, the bodies are finer, but of larger areal extent. Still farther southeast, they are still finer and again of small area.

A similar situation exists in the Pleasantville district. Northwest of Pleasantville the sands occupy a rather narrow belt, but are quite coarse and the pay beds are thick. South of Pleasantville the sand bodies are of larger areal extent but finer. Near the southeast corner of the quadrangle, the sand bodies are small, though rather rich in places.

Starting at the Hamilton Corners district, which lies off the west edge of the quadrangle near Prather School, the sand is coarse and rich. To the southeast there are small scattered pools for a distance and then a rather large pool near the southwest corner of the sheet.

Saegerstown shale. Below the First Sand are about 50 feet of dark gray shale with rare, thin beds of sandy shale and a few thin beds of fine silty sandstone and limey sandstone. The name Saegerstown was proposed by G. H. Chadwick in 1925 (11, p. 457).

Second Sand formation. The Second Sand formation has a total thickness of 45 to 70 feet. Where completely developed, as south of Pleasantville, it consists of an upper sandstone, the Red Valley sand, 20-25 feet thick, 25 feet of shale, and a lower sandstone, the Second sand, 20 to 30 feet thick. These sandstones were called the Second A and B sands by Carll in 1875. They have been called the Bimber Run conglomerate and the Pope Hollow conglomerate by Caster (7, pages 86 and 87), although his discussion of their distribution is misleading. They are not as well exposed in Bimber Run as they are in other places in the vicinity, and their thickness apparently does not exceed 30 feet anywhere.

The Red Valley sand has a sharp northwestern margin which is an almost perfectly straight line bearing N 43° E and passing through the southeast corner of the borough of Pleasantville. Northwest of this line the sand is very seldom noted in well logs, and more than a mile northwest of it, it is represented only by very thin and fine sandy beds which are distinguishable from the Saegerstown shale above only by electric logs. To the southeast the sand rapidly acquires a thickness of 15 to 23 feet, very seldom being over 25 feet in thickness. The sand is generally fine, but contains pebbly beds in places, especially at or near the base. The productive oil pools are all in a belt two miles wide whose northwest edge lies near the edge of the sand. Southeast of the thick belt the sand becomes thinner, finer, and quite shaly. Near the southeastern corner of the quadrangle there are beds of green and reddish shale.

The shale member is dark gray and has a rather constant thickness of 25 feet. The top of the Second sand lies from 45 to 55 feet below the top of the Red Valley sand.

The Second sand shows a strikingly similar picture. Its northwestern edge is a nearly straight line striking N 40° E and passing 2 miles northwest of the borough of Pleasantville. Its edge is, therefore, almost exactly parallel to the edge of the Red Valley sand, but 2½ miles farther northwest. The sand thickens rapidly southeastward to about 25 feet, and south of Pleasantville forms a very uniform sand body, 20 to 30 feet thick and 4 miles wide. The sand is for the most part fine, but frequently contains pebbly beds, especially at the top. All the productive pools are within this belt. North of Pleasantville the sand is usually thin and hard and not very productive. Northwest of the thick belt, the sand is only a thin, fine "shell".

Toward the southeast, the Second Sand formation begins to assume the aspect of a true red-bed series. The shales, and to a certain extent the sands, become light red or bright green. The sands are present, but thinner and finer, and although they usually contain oil, they are seldom commercially productive.

Amity shale. From 55 to 65 feet below the Second Sand formation, the section consists almost entirely of shale, usually dark gray but occasionally with reddish beds. This member was named the Amity shale by Chadwick in 1925 (11, p. 455-464).

Third Sand formation. The Third Sand formation is 75 to 100 feet thick, and consists of beds of sandstone with intervening beds of shale. The upper 20 to 25 feet of the Third Sand formation consists of beds of fine to medium-grained sandstone, seldom exceeding 5 feet in thickness, and beds of sandy shale and shale. These sandy beds are rarely reported in well records, since they seldom or never contain appreciable amounts of oil. Electric logs have shown that they contain water in certain localities. It is possible that they are the equivalent of the Boulder and Shira sands of the Hilliards quadrangle (2).

The top of the Third Stray sand lies about 20 feet below the top of the Third Sand formation (490 feet below the top of the Corry sandstone). It is widespread over the quadrangle, and subsurface structure contours have been drawn on the top of this bed. It ranges in thickness from 2 feet to 60 or 70 feet.

The Third Stray sand is thin or absent northwest of a line striking N 51° E and passing through the northwest corner of the city of

Titusville. Southeast of the line it is present, but is not at all uniformly developed. Its thickest development is south of the borough of Grand Valley, where it consists of a series of parallel "streaks" or bars. These bars are 1,000 to 2,000 feet wide and strike from N 50° E to N 65° E. The maximum thickness decreases from 60 feet near Grand Valley to 20 feet on Goodwill Hill, increasing again to 40 feet at Colorado. Between the bars, the sand is about half the maximum thickness and is shaly. Pebbles are common only in the thickest northwesternmost bars. The bars in the quadrangle range from 1 to 5 miles in length, but the southernmost or Colorado bar extends eastward to Tidioute as a long, narrow, and very thick pebbly bar with an over-all length of nearly 10 miles.

The sand is present, but thin and shaly at Dotyville, and also north of Titusville, where it has a maximum thickness of 25 feet. It is also present at Breedtown, where it does not exceed 15 feet in thickness.

Over a belt 3 to 4 miles wide passing southeast of Titusville the sand is missing, but reappears at Pleasantville, from which point it extends northeastward to Fagundus (on the Tidioute quadrangle) and southwestward to Petroleum Center. It has here lost its streaked character, and consists of a uniform sheet of sand, usually coarse and often pebbly, from 5 to 15 feet in thickness. Southeasterly from Pleasantville the sand contains a good deal of shale and sandy shale, except that at Pithole and Cashup it increases to 15 feet in thickness and is coarse, pebbly, and very porous.

The top of the Third sand lies 35 to 45 feet below the top of the Third Stray sand. Where the latter is abnormally thick, as at Grand Valley and Triumph (in the Tidioute quadrangle), it has apparently cut its base downward through the intervening shales and sandy shales, into and perhaps even below the Third sand.

Like the Third Stray, the Third sand is characteristically streaked. Its western edge is a line passing through the western part of the city of Titusville and striking N 15° E. West of this line the sand is present, but thin, shaly, and unproductive of oil. The edge of the sand is smooth, but not straight, containing several offsets. East of this edge, the sand thickens rapidly to 50 or 60 feet, where it contains pebbly beds throughout its entire thickness. It also contains, however, beds of fine sandstone and even shale. Eastward from the thick zone, the sand becomes thinner and finer. The pebbles disappear, and shale beds occupy more of the section.

In the southwestern part of the quadrangle at Petroleum Center and Pioneer, the sand is present in curved streaks and lobes, like the fingers of a hand. This body resembles the curving bars with intervening swamps of the Presque Isle peninsula at Erie. Northeastward along the same trend, the Shamburg pool is streaked in its southern part, but is intersected at right angles in the central part by an impervious belt a few hundred feet wide, north of which the sand is thinner and contains no pebbles. From the Shamburg pool northeastward, the sand is present, but thin, fine, hard, and in patches.

From Petroleum Center through Pioneer, Shamburg, and Pleasantville to Grand Valley, the sand exhibits a trend which is roughly parallel to the westernmost Octave-Titusville-Church Run body. Between these trends, the sand is thin and shaly, except for a curious lump of nearly pure pebble sand, 60 feet thick, at Dotyville. Another curious thick spot is at Miller Farm, but here the sand is blue and shaly. Cores are not available.

Origin of the Venango Oil Sand group. Speculation concerning the origin and mode of deposition of the Venango Oil Sand group will be withheld until the final report on the area, when general sand maps of the entire district can be presented. Certain facts have, however, become clear from the work to date.

The sands show all the characteristics of near-shore deposition The sand and shale beds are as a rule thinly interbedded, and cores from the sands have frequent highly irregular shaly partings suggesting ripple marks. Cross bedding has been noted in a few diamond cores from the area. Clay balls are very common and suggest wave action. Pebbles are common and are set in either a sandy or a shaly matrix.

The general geology of western Pennsylvania indicates that the sea must have lain to the northwest and the land to the southeast. The upper Devonian strata change their character from thick sands and redbeds, obviously laid down in a continental environment in central Pennsylvania, to rather thin shales and limestones, laid down some distance from the shore of a shallow sea, in Ohio.

It seems likely that the Venango oil sands were laid down near the shore line. The three members show three different types of deposition. The First Sand type consists of irregular sandy zones, which trend roughly in a northwest-southeast direction, and which tend to be coarser near the northwest ends. The Second Sand type consists of uniform belts of sand trending northeast and southwest, with a smooth northwestern edge, grading into shales and redbeds toward the southeast. The Third Sand type consists of thick, narrow bars and streaks, often very pebbly, and either single or multiple. They are more irregular than the Second Sand belts, but thicker and more consistent than the First Sand bodies.

CHEMUNG GROUP

The nomenclature of the Upper Devonian of western Pennsylvania and southern New York is in a rather confused state. The limits of the Chemung group have been repeatedly shifted (3, p. 145). The beds for approximately 1,000 feet below the Venango group belong to the Chemung in its older usage, and to the Conneaut and Canadaway groups of more recent usage (13).

In the Titusville quadrangle about fifty wells were found that penetrated deeper than the Third sand, and it is believed that about that many more may have been drilled and all records of them lost. Reliable records could be secured for only about twenty of them. However, partial sets of drill cuttings from two wells were examined.

The dark gray shales characteristic of the Venango group continue for 100 to 150 feet below the base of the Third sand. At this depth a series of alternating red shale, greenish gray shale, and fine silty sandstone begins, which is known as the "Red Rock." Sand beds are occasionally reported as occurring in this series, sometimes with a show of oil, but they are nowhere commercially productive.

The Red Rock continues 440 to 475 feet below the base of the Third sand (about 980 feet below the top of the Corry) where the rock contains more sand and is noticeably harder to drill. To the east, in the Tidioute quadrangle, production of oil and gas is obtained from sands in this zone. The principal horizons are the First Warren sand, the Second Warren sand, the Queen sand, the Clarendon sand, and the Speechley sand. In the Titusville quadrangle none of these sands is productive of either oil or gas. The drill cuttings show them to be exceedingly fine silty sandstones and sandy shales. The drillers' logs are not at all consistent about the position of the sands, but there seems to be a definite sandy zone starting at about 620 feet below the base of the Third sand, which is the Queen, and another about 900 feet below the Third sand, the Speechley. Very small shows of gas have been reported from these zones, but considering the number of wells that have been drilled and the tendency for the sands to become fine and shaly towards the northwest, it is considered unlikely that commercial production of either oil or gas can be obtained from them.

Four wells have been drilled deeper than the Speechley sand, but did not encounter productive sands. So far as is known, the Watson deep well, drilled in the early 1870s to 3,553 feet, is the deepest well in the quadrangle. No record was preserved of this well, to the understandable grief of the early geologists (9, p. 154).

Deeper strata. Since there are no very deep wells in the quadrangle, this survey has contributed nothing to the understanding of the rocks below the Chemung formation. Those interested in deeper sands are referred to general works on the deep sands of northwestern Pennsylvania (14, 15, 16).

STRUCTURE

Regional

The Titusville quadrangle lies in the northwestern part of the Pittsburgh-Huntington synclinorium, a broad, shallow, spoon-shaped fold, whose lowest part lies in West Virginia. Well-defined anticlines and synclines are found on the southeastern side of this synclinorium, but on the northwestern side there are only low and rather irregular deviations from a general southerly and southeasterly dip.

Local

Structure contours have been drawn on the top of the Red Valley sand and on the top of the Third Stray sand. The latter is the more widespread, and where it was missing the proper interval (35 to 45 feet) was added to the elevations of the Third sand, so that only a small area in the northwestern part of the quadrangle is not included in the structure map.

In general, the sand dips nearly due south, from an elevation of 1,040 feet at the northern edge of the quadrangle to about 630 feet at the southern edge, an average fall of 23 feet per mile.

The principal structural feature within the quadrangle is a syncline trending in a northeasterly direction. It enters the quadrangle from the south near Kaneville, and as far as Miller Farm it is not well-defined. From Miller Farm it passes between Pleasantville and Enterprise, leaving the quadrangle about a mile north of Pineville.

Southeast of this syncline the sand rises to an anticlinal axis which is well-defined from Neiltown to Tyrrell Farm School, but becomes less definite toward the south. This is the continuation of the Fagundus anticline of the Tidioute quadrangle (1, p. 4).

Both anticline and syncline plunge to the southwest, and there is no structural closure at the Third Stray sand horizon.

Faults of small displacement probably occur at numerous places in the quadrangle. Half a mile south of Maple Grove School, the Third sand of the Church Run streak gently rising to the north, is dropped fifteen feet between adjacent wells, probably by a fault. The wells were drilled by a competent and thoroughly reliable driller, and the elevations were carefully checked. Unfortunately, the streak is only one well location wide at this point, so that it was impossible to determine the strike of the fault or monocline.

A small reverse fault, whose plane dips east or southeast about 45° and which has a vertical displacement of six feet, is exposed along the railroad, about 1,500 feet above Miller Farm bridge, four miles south of Titusville. Its strike appears to be a little east of north, but could not be determined closely. A similar small reverse fault with the southeast side up was exposed in excavations for the spillway at the Tionesta dam, three miles southeast of the southeastern corner of the quadrangle.

Small irregularities in the surface of the Third Stray sand are noticed where that sand, or the underlying Third, is abnormally thick. South of Grand Valley the thick streaks are reflected in wrinkles on the top of the sand. At Dotyville the Third Stray sand shows a small dome 20 feet high over the thick Third sand. There is a similar dome at Shamburg and anticlinal wrinkles over the Church Run and Octave pools. These highs are due to the fact that the shales have suffered more compaction than the sandstones, and have no structural significance.

OIL GEOLOGY

Accumulation of oil and gas

Within the Titusville quadrangle oil and gas occur only where there are sandstones of considerable porosity and permeability, and it is the location of the sandstone beds that determines the location of the pools. Some porous beds do not contain oil or gas, notably the Corry sandstone, which crops out quite generally in the valleys in the quadrangle, and which usually contains fresh water. The First Sand formation, which crops out in the deep glacial valleys in the northern part of the quadrangle, also frequently contains fresh water. No extensive sand body below the First sand contains salt water to the exclusion of oil. The Second sand near Shamburg is reported to contain salt water, and there are several districts in the Third and Third Stray sand that have been accidentally flooded.

Structure apparently has had little effect in segregating oil and water within the quadrangle. Naturally-encroaching edgewater has never been known to exist. Connate water is present in both productive and non-productive sand beds, as shown by core analyses, but seldom saturates the sand. The lack of segregation between water and oil may be ascribed to the lenticularity of the pay sand beds, which can seldom be traced more than a few hundred feet laterally, and to the low dip of the strata. Under these circumstances gravity has less effect than the capillary pressures of the fluids (26).

Gas, however, with a much lower viscosity and a much greater density differential, is more likely to be segregated by structure. It is a general rule that gas is or has been more abundant at the northernmost, that is, the higher ends of the various sand bodies.

Petrography of the sands

Texture. As has already been stated, the sands range from an extremely fine and silty character to coarse, pebbly conglomerates. As a general rule they are thoroughly cemented by secondary silica, and may be properly called quartzites. Thin sections show that the grains are cemented by secondary silica overgrowths, which partake of the crystal axis of the original quartz grains, and which join the adjacent grains in an irregular manner, frequently resembling the sutures of a jig-saw puzzle. The surfaces of most of the smaller cavities are bounded by plane crystal faces, and many of the cavities are completely filled with calcite. The finer the grain size the more complete the secondary silica cementation; the coarser pebble rocks are in places quite loose and friable, and the pebbles are not overgrown. In some coarse soft pebble rocks small, loose, perfectly-shaped quartz crystals are common. Many of the pebbly beds consist of pebbles in a hard shaly and ferruginous matrix. Veins of quartz up to an inch in thickness, with vugs and geode cavities, were noted in two cores. In another core small veins of galena have been found.

Grain size. Numerous screen analyses of the sands of the Venango group have been made. Fettke (17) has tabulated twenty from the First sand at Hamilton Corners. These have been plotted as histograms in Figure 1.

William L. Hershelman in 1937 made screen analyses of oil sands of the Goodwill Hill district. Eight of these are plotted in Figure 2.

The histograms show the great variation in size of the particles. However, several show a remarkable degree of sorting. Some samples have 50 percent or more of the grains in one or two grades, most commonly between 0.1 and 0.2 millimeters.

Because of the secondary silica cementation it is difficult, if not impossible, to make an accurate grain-size analysis. The fine grades consist partly of crushed grains, and the coarser grades consist partly of aggregates, which are impossible to reduce without further crushing. Because of this cementation, it is questionable whether attempts to relate grain size and porosity or permeability in the Venango sands will yield important results.

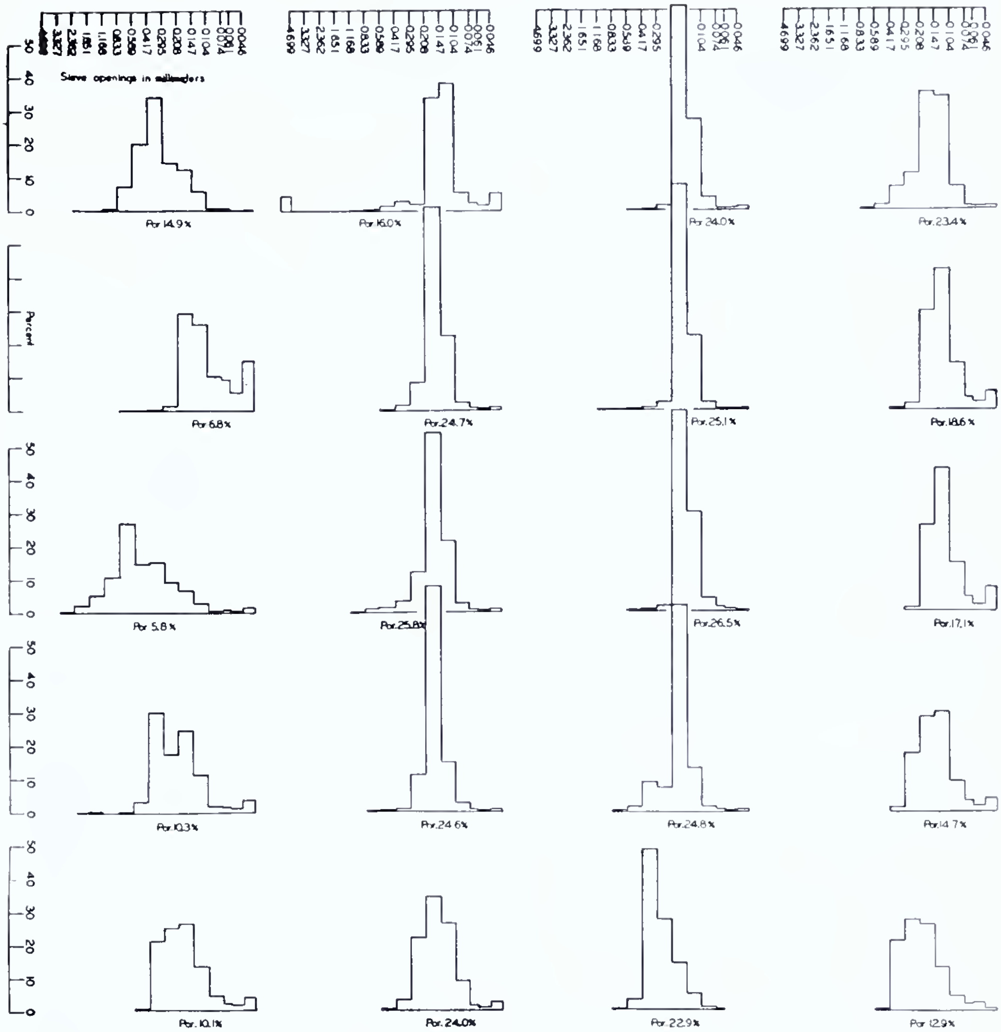

Figure 1. Grain-size histograms of First Sand near Hamilton Corners. (After C. R. Fettke)

Composition. The pebbles are principally white quartz. Yellow quartz is common and red jasper is rare. Fragments of igneous and metamorphic rocks are absent or exceedingly rare. The sand grains are clear quartz, and feldspars are comparatively rare. Muscovite mica is abundant. Ilmenite and magnetite are common. Hematite, limonite, siderite, and pyrite are abundant and doubtless authigenic, that is, formed in place by percolating solutions, and not deposited as water borne grains like the quartz. Heavy minerals are scarce and show remarkably few species. Zircon and tourmaline constitute the bulk of them. The tourmalines are of various colors and occasionally show euhedral overgrowths on rounded grains. Barite is locally common and is undoubtedly authigenic. The titanium minerals, rutile, anatase, and brookite are present in nearly every sample. Garnet, chlorite, and zoisite are rare. The heavy minerals in samples from a well in the Goodwill Hill district are shown in table 2 as percent of total nonopaque heavy minerals.

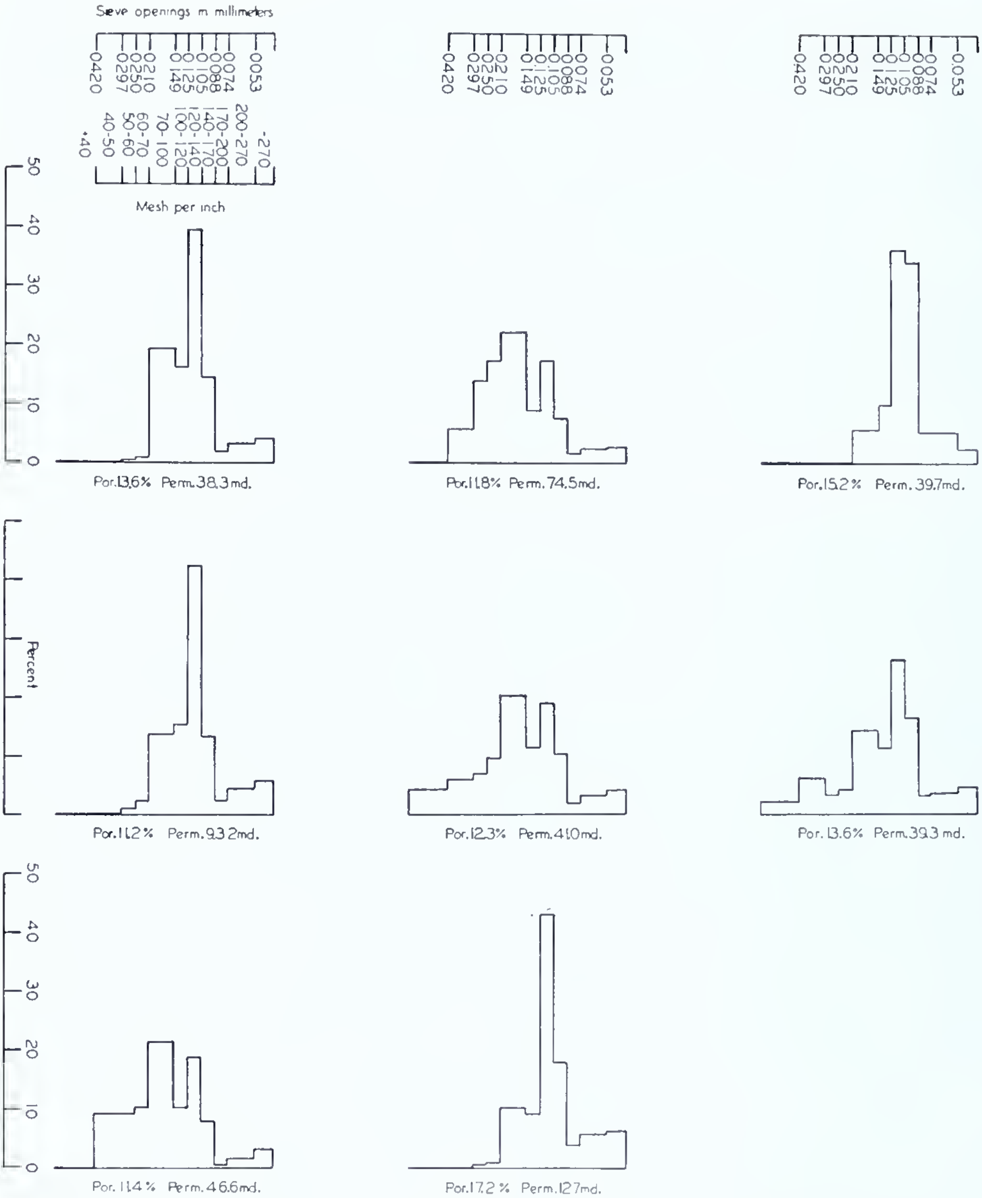

Figure 2. Grain-size histograms of First and Third Sands in Goodwill Hill District. (After W. L. Hershelman)

The striking features of the heavy mineral suite are (a) its remarkable constancy in percentage and (b) its lack of any but the more resistant species of minerals. These indicate that the source of the sands of the Upper Devonian through the Mississippian was essentially the same, and that it consisted almost entirely of sedimentary rocks, or of a sedimentary series which has been only slightly metamorphosed (20). If the sands had been derived from either an igneous or metamorphic mass there would have been far more variety of minerals, and in particular, hornblende, epidote, andalusite, sillimanite, and cyanite should have been common. Of several thousand grains identified, there was one doubtful hornblende and a few doubt-

TABLE 2.

*Heavy minerals in drill cuttings from oil well on Goodwill Hill.**

Depth	Horizon	Zircon		Tourmaline			Rutile	Anatase	Brookite	Garnet	Chlorite	Zoisite	Barite
		Sharp	Rounded	Brown	Green	Blue or mauve							
68–72	Shenango shales	26	61	4	3	1	4	½	½				
80–84	Shenango ss.	21	61	9	2	2	3	1		½			
106–111	Shenango ss.	19	61	8	3	2	5					1	
171–176	Cuyahoga group	17	56	14	6	3	2				1		
221–226		26	57	5	4	4	4						
246–251		23	59	4	⅓	2	2						10
261–266	Corry ss.	13	59	17	3	4	1	½			½		1
276–281	Corry ss.	15	70	7	1	3	1			½			1
333–338	Cussewago ss.	17	62	9	6	3	2				1		
366–371	Cussewago ss.	17	57	8	9	1	½	½					8
445–450	Riceville sh.	16	65	10	5	2	½				½		½
502–508	First sand	9	74	12	3	2					½		2

* Percent of total non-opaque crop. Opaques not counted.

ful sillimanites. The presence of traces of chlorite and zoisite indicates that perhaps a very small proportion of the material was derived from a metamorphic series, but these may also have survived a period of enclosure in older sedimentary beds.

The sands have thus passed through at least one cycle of previous transportation and deposition. They may have been lithified previously, since some pebbles consist of quartzite. They would be expected to be thoroughly rounded, but are exceedingly angular in shape. This angularity is due to the secondary silica overgrowths, and to the unavoidable crushing in reduction to grain size.

Porosity and permeability. The porosity and permeability of the sands of the Venango series are exceedingly variable. The porosity ranges from 5 percent or less to a maximum of about 20 to 25 percent. The average for the producing sands is in the neighborhood of 15 percent. The permeabilities range from essentially zero for the fine, silty, shaly sandstones to 4,000 millidarcies for the coarse pebbly sands. The pebble beds are, however, frequently thoroughly cemented with shale and ferruginous material, and may have very low permeabilities. Most of the best productive sands range between 10 and 500 millidarcies in permeability.

Several hundred cores have been taken within the Titusville quadrangle. As a rule samples are tested for permeability every four to six inches, and for porosity and oil and water content every foot or two, depending on the lithology of the sand. Characteristic core analysis profiles of two wells 300 feet apart in the Goodwill Hill pool are shown in Figure 3 and of two wells near Pioneer in Figure 4.

Oil content. The oil content is determined by various methods, and usually expressed as saturation, or percent of total pore space occupied by oil. The laboratory which has analyzed most of the cores used in compiling the reserve estimates in this report extracts the oil with a solvent, usually carbon tetrachloride, and the resulting

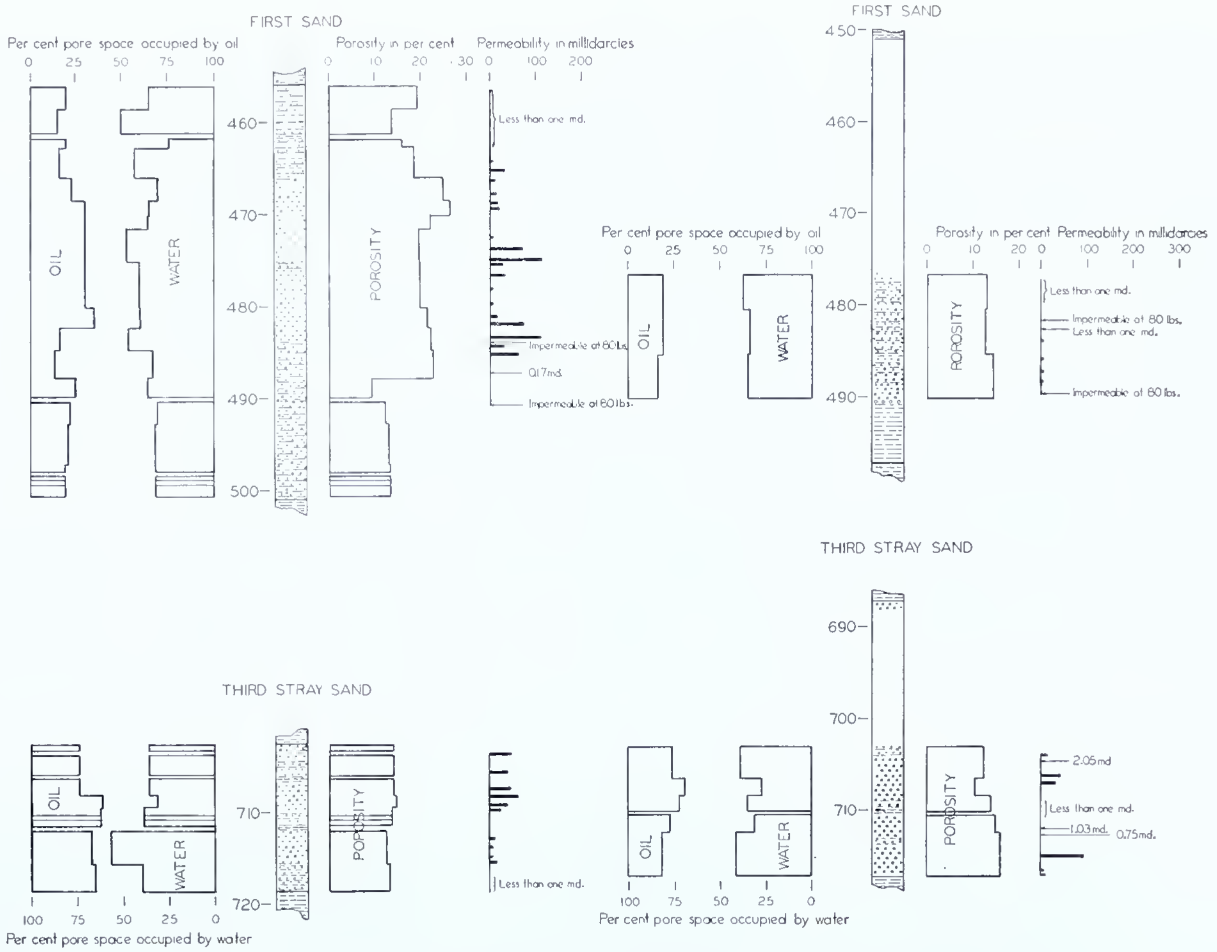

Figure 3. Characteristic core analysis profiles of two wells about 300 feet apart in the Goodwill Hill District.

solution is compared colorimetrically with standard solutions of the same oil. The value is checked by the loss in weight of the sample and the amount of water. The latter is determined by extraction with xylene according to A.S.T.M. standards. Other laboratories use the retort methods of determining oil and water.

The oil content of the producing sands ranges from 10 or 12 percent to 40 or 50 percent of pore volume saturation, although most analyses show less than 30 percent. It is questionable whether much oil will be produced from a sand less than 20 percent saturated. Expressed as barrels per acre-foot, the oil content ranges from 100 to 350 or 400, with an average for all sands between 250 and 275 barrels per acre-foot. Cored wells showing an average of less than 150 barrels per acre-foot produced very little oil.

Water content. The water content ranges usually from 40 to 60 percent. The water saturation has an important influence on recovery by air drive. It seems likely that the oil saturation can be reduced to 20 percent or less only when some water is present, so that a considerable amount of the grain surface is wet with water. With high water saturations, however, the permeability of the rock to oil becomes very low, and little or no oil can be recovered.

There are few places in the quadrangle where only salt water is produced from a sand. The Second sand often produces considerable quantities of salt water, and electric logs indicate that the water may be confined to certain beds. In nearly all fields a good deal of salt water is produced with the oil, but it is not known whether it is coming from the same beds as the oil or from adjacent strata.

Estimation of Reserves

In making estimates of the reserves of oil in the Titusville quadrangle, the analyses of more than 500 cores were used. These are fairly well distributed throughout the quadrangle and are lacking only from the Breedtown pool.

For every sand but the First sand, the sand thickness maps were divided into small areas to which were assigned, on the basis of the cores, a certain number of barrels per acre-foot. Each small area was then measured by planimeter and the area in acres multiplied by the average thickness and the number of barrels per acre-foot.* Studies based on both laboratory work and field evidence have indicated that only the oil in excess of 150 barrels per acre-foot is recoverable. A separate computation was made, using the number of barrels per acre-foot in excess of 150, to determine the amount of oil recoverable by secondary methods of recovery now in use. This figure will be larger than the actual expected recovery, since to reduce the oil content to near 150 barrels per acre-foot requires close well spacing and intensive application of air, gas, or other secondary recovery medium.

The method of estimating reserves by computing the number of acre-feet in small areas could not be applied to the First sand, since the sand bodies are so irregular that it was impossible to draw thick-

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* Values assigned ranged from 200 to 350 barrels per acre-foot.

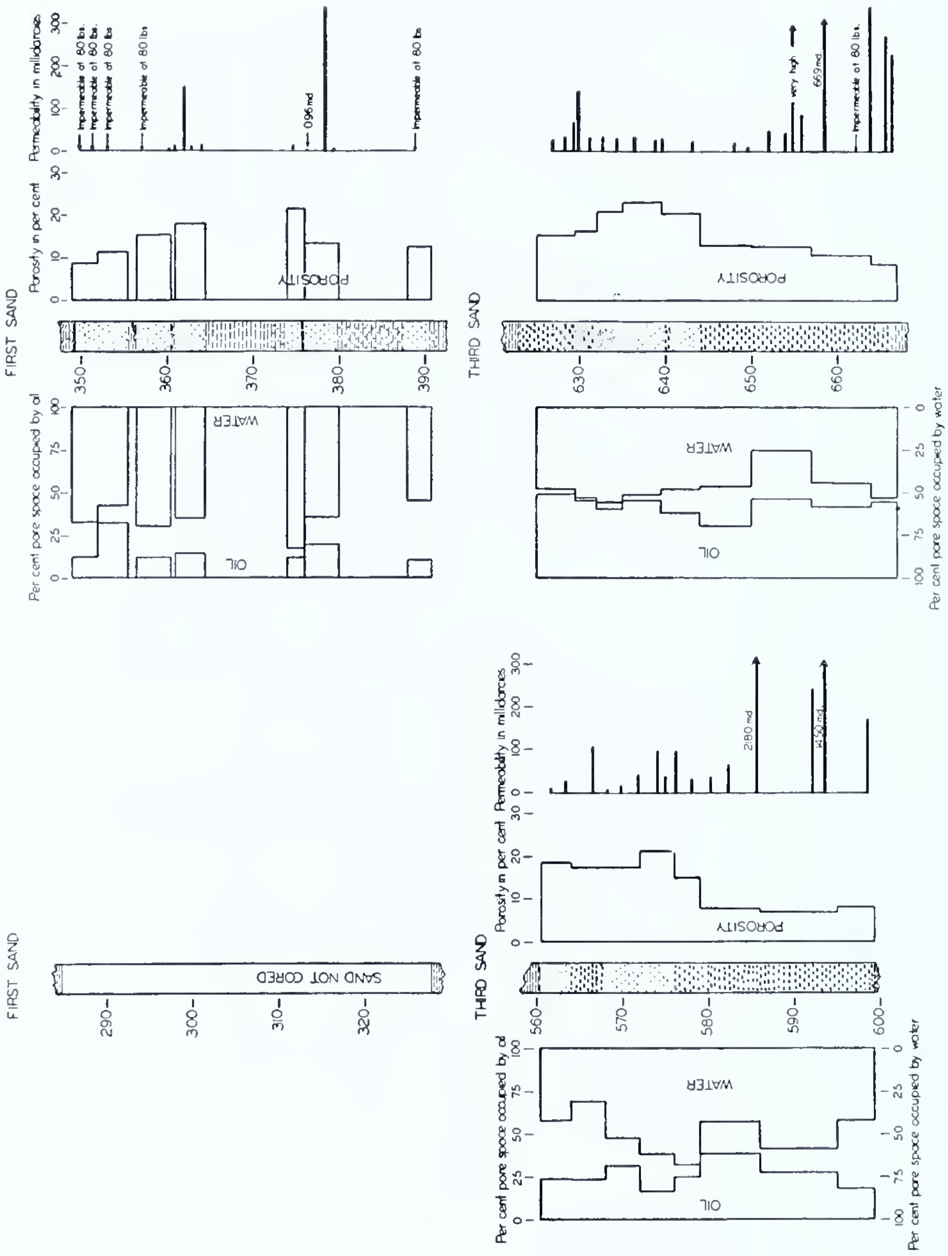

Figure 4. Characteristic core analysis profiles of two wells about 300 feet apart in the Pioneer District.

ness maps. The First sand was divided into similar small areas, a total barrels-per-acre value assigned to each area, and the total oil in each area computed. Since, for the other sands, the oil in excess of 150 barrels per acre-foot averaged about 40 percent of the total, it was assumed that 40 percent of the oil in the First sand is recoverable.

It is considered unwise to present reserve estimates completely broken down into different pools, since an error in assigning the proper value to a district might, if published, cause an undeserved appreciation or depreciation of its value. Estimates for certain of the more important individual pools are shown. The reserve estimates have been based on all the information available and have been prepared with care. They are believed to be as accurate as possible at the present time.

TABLE 3.

Reserves of oil in the Titusville Quadrangle.

Sand	Productive acreage	Total oil, barrels	Recoverable oil, barrels
First	14,580	64.460.000	25,784,000
Red Valley	8,897	43,494,000	19,921,000
Second	9.595	46,240,000	19,200,000
Third Stray, Black Oil District	8,170	19,793,200	7,110,000
Third Stray Elsewhere	16,635	57,360,000	21,101,000
Third	18,513	125.249.500	46.492.600
	76,390*	356,596,700	139,608,600

* Total acreage of sands. Actual productive area is 42,830 acres.

Economically recoverable reserves. Although it is probably physically possible to recover about 140,000,000 barrels of oil from the Titusville quadrangle, it is doubtful whether it will ever be economically profitable to do so.

It is clear that for a repressuring operation the investment in wells, plant, and operating expenses will be approximately the same for any acreage, but the oil produced will depend on the thickness of the pay sand and its oil content. Thus different leases, for any particular price of oil, may be classed as profitable, paying, or unprofitable. Certain leases are profitable at a price of oil of $1.75 a barrel, while others would be unprofitable to operate at $4.00 a barrel. Many leases in the quadrangle may be classified as marginal, that is, profitable to operate only when the price of oil is high. These facts should be borne in mind by those desiring to invest money in the area. The actual oil content of any lease may be estimated by studying the production history and well records, and may be determined with some assurance by drilling and coring one or more wells.

The estimate of reserves given above may therefore be misleading. For example, ten feet of sand with a recoverable oil content of 100 barrels per acre-foot might be profitable to operate if there were twenty feet of another good sand above or below it, but quite unprofitable alone. The economically recoverable reserves in 1940 are a rather small fraction of the physically recoverable reserves, but they might be doubled or tripled by an increase of $1.00 a barrel in the price of oil.

PRODUCING OIL SANDS

GLACIAL SANDS

Oil was found on Watson Flats at a depth of 15 feet in glacial gravels, in April 1877. The sand and gravel filling the valley is capped by a layer of impervious, tough, blue clay. It was suggested by Carll (9, p. 425) that the oil seeping up from the underlying oil series was trapped under the impervious clay in a small reservoir. Only a little over an acre proved productive, and Carll estimated in 1879 that about ten or twelve thousand barrels had been recovered.

BEDS ABOVE VENANGO SAND GROUP

The Corry and Cussewago sandstones, or their probable equivalents, yield oil and gas in districts to the south and east of Titusville, but there is no record of their having contained appreciable quantities of oil or gas within the quadrangle.

The Drake well, drilled in 1859, was completed August 27 at a depth of 69½ feet. The producing sand was undoubtedly a stray sand in the lower part of the Riceville shale. Thin, fine sands were noted in the samples and electric logs at about this horizon. A well drilled in 1939 (257 on map) about half a mile north of the Drake well encountered a 2-foot sand at this horizon, which produced water and a small amount of oil. The oil was black, viscous, and with an A. P. I. gravity of 28°. The sand undoubtedly crops out under the drift a short distance to the north, and it is likely that the water in the buried valley provided the pressure necessary to force the oil up Drake's well. The Drake well produced from eight to ten barrels a day for some months.

A general discussion of the Venango sand group will be found in a previous section. The following sections discuss the sands as they are found in the various producing districts.

FIRST SAND

Goodwill Hill-Grand Valley. In the northeastern quarter of the quadrangle the First sand has been productive at many localities.

Two miles north of Cutler School much gas and some oil were found in numerous small pools about 1920. One well produced several million cubic feet per day when first drilled in, and a pipe line was built to Erie but the well was exhausted in a few months. In places the sand is 20 to 30 feet thick but the pools are of small area.

About ¾ mile north of Cutler School is an irregular pool elongated in an east-west direction covering about 200 acres. The sand is recorded to be 20 to 40 feet thick. In the eastern part there are two pay beds, separated by shale, the upper of which is pebbly. To the southeast are two small active pools and one abandoned, with a combined area of 80 acres.

A somewhat larger pool southeast of Cutler School has a productive area of about 220 acres. Several cores taken in the pool show the aggregate of the productive beds to be as much as 35 feet. The upper part is usually quite pebbly, the lower part only occasionally so.

About 3/4 mile northeast of Selkirk is a pool which is principally productive in the Third sand, but some First Sand oil also is produced.

Southwest of Grand Valley 1 3/4 miles is a pool trending southeast and covering about 120 acres. The First sand consists of alternating shale, sandy shale, and sandstone, with some pebbles at the base only. The sand body is cut to the south by the valley of Caldwell Creek, where it crops out under the valley fill.

Southeast of Caldwell Creek Valley is a large and irregular area where the First sand is productive. The sand is extremely variable, and the thickness shown in the well records changes greatly within a few hundred feet laterally. The "pay" beds seem to occur more persistently in the lower part of the sand, but in many places the whole section is shaly and impermeable. Pebbles are very rare within the formation, but are often found in the top and base.

Production from this sand is of fairly recent date. During the early drilling, the Third Stray sand was the objective, and most of the older records do not show the First sand as present. The productive area, with outliers, embraces 2,750 acres, and is estimated to contain 17,000,000 barrels of oil, of which 40 percent or 6,800,000 barrels are estimated recoverable.

Pleasantville pool. The largest First Sand pool lies west and south of Pleasantville. In the northwest lobe the basal part of the sand is rather consistently a coarse sandstone, pebbly in certain beds. The upper part is variable and frequently shaly and not shown in the well records. In places an upper pay is separated by ten feet of shale from the lower pay. The sand is characteristically coarse and has an unusually high porosity, from 19 to 23 percent. The permeability ranges up to 1000 md.

South of Pleasantville the sand is generally present, although not so rich. It consists principally of alternating beds of shale, sandy shale, and sandstone. Well logs record 20 to 40 feet of sand, but the aggregate of actual pay-sand beds is much less, seldom reaching 20 feet.

In the northern lobe, and to a lesser extent in the southern part, the pool is operated with air drive. It is estimated to embrace 4,400 acres with a total oil content of 16,930,000 barrels, of which perhaps 40 percent, or 6,772,000 barrels is recoverable.

An outlying pool 1 1/2 miles west of Jerusalem Corners contains up to 25 feet of pay sand, in places porous and well saturated.

Asbury Chapel. Near the eastern edge of the quadrangle are three pools of First sand oil; south of Neilltown, east of Asbury Chapel, and northeast of Washington School. Some of these pools have been shown by cores to be quite rich, but the good sand is of limited extent. Some First sand is also recorded in the Cashup district. Altogether these pools underlie 920 acres and are estimated to contain 3,980,000 barrels of oil, of which perhaps 1,600,000 are recoverable.

Shamburg-Pithole. South of the Pleasantville pool, and possibly continuous with it, is a long but rather narrow area extending from Shamburg to Pithole, under which the First sand is productive. In the western lobe well records show as much as 40 feet of sand, but only a small portion is pay. In the southern lobe 10 to 30 feet of sand are recorded, but cores have shown it to be quite shaly, except for certain rather rich localities. North of Pithole the First sand has been known locally as the Quinn sand. The total area contains 1,310 acres, and the sand is estimated to contain 4,770,000 barrels of oil, of which 1,908,000 is recoverable. The sand is reported to contain water along the concave southern edge of the pool.

Pools in southern part of quadrangle. The First sand is generally present in the southwestern part of the quadrangle, and is locally productive. Core analyses range between a few hundred and seven thousand barrels per acre.

The First sand is productive in several places in the vicinity of Russell Corners where well records show 40 to 60 feet of sand, of which occasionally as much as 30 feet is pay.

North of Oakland Church is a pool of First Sand oil . The pay sand is in the lower part of the formation, and ranges from 9 to over 20 feet in thickness. It is usually called the Amber sand in this district.

These pools total 2,650 acres and contain about 9,000,000 barrels of oil, of which 3,620,000 may be recoverable.

Cherrytree Township. Throughout most of Cherrytree Township are small scattered spots where the First sand is productive. A small productive area about one mile north of Cherrytree was discovered in 1939. The most important pool is in the vicinity of Prather School, where there may be 30 to 40 feet of pay sand. The upper part frequently contains fine pebbles and has thin shale beds. The lower part is in places clear soft sand. Both porosities and permeabilities run higher than normal, and the sand is well saturated. Pebbles are occasionally found in the small pools to the east, but the sand is generally shaly and with a low porosity. The pools aggregate 1,000 acres, and contain about 4,300,000 barrels of oil, of which 1,720,000 barrels are recoverable.

Northwestern part of quadrangle. Well records show the First sand to be present throughout most of the northwestern part of the quadrangle. It is generally reported but usually full of water in the Church Run pool north of Titusville. Scattered wildcat wells in Rome Township usually record it as present, sometimes with small amounts of gas and a show of oil, and usually with considerable quantities of fresh water. There are no commercially productive pools.

RED VALLEY SAND

In the Carsonville, Pineville, and Neilltown districts the sand is mostly massive (''clear''), especially in the upper part. There are occasional shale breaks and some pebbly beds. The latter may be anywhere in the sand but are characteristically near the top or bottom, more often near the bottom. The permeability is usually rather low, seldom as much as 300 millidarcies. The porosity is 15 to 18 percent, the oil saturation 25 to 27 percent, and the average oil content from 250 to 350 barrels per acre-foot.

From Pleasantville to Pithole the sand is very similar. Pebbles are generally found near the base, except along Pithole Creek north of Pithole where they may be found throughout the bed. The oil content ranges from 200 to 300 barrels per acre-foot.

Southeast of the main productive belt the sand is somewhat thinner, seldom reaching 20 feet in thickness. The sand is apt to be hard, relatively impermeable, and frequently broken by shaly beds. Although there is very little production in this area, much of the sand is possibly oil-bearing. The general lack of gas pressure and the impermeability of the sand make its development unprofitable.

The oil is of an amber color and the A. P. I. gravity ranges from 45° to 48°. Most of the oil production comes from leases which have been subjected to air drive, either with air alone or air and gas.

The Red Valley sand is productive over an area of 8,900 acres. It is estimated that there are present in the sand 43,500,000 barrels of oil, of which 20,000,000 would be recoverable by intense application of air drive.

The Red Valley sand apparently derives its name from a district near Rockland Station on the Allegheny River above Emlenton. It is called the Rosenberry sand in northern Butler County (2). Between Pleasantville and Tidioute it is generally known as the Second sand (1). Near Pleasantville it is commonly called the Lytle sand. Since over a large part of the productive area around Oil City it is called Red Valley, and since the name has seldom been misapplied, it is suggested that the name is the most suitable for this sand in the Venango fields.

SECOND (SALT) SAND

East of Pleasantville the Second sand ranges from 10 to 20 feet in thickness. Characteristically a bed of pebbles is at the top. The middle part is usually massive sand, and the lower part is often pebbly, though in places it becomes shaly.

South and southeast of Pleasantville usually the upper part of the sand is uniform with a permeability of about 50 millidarcies, and the lower part is apt to be broken with beds of shale. There is frequently a pebbly bed in the middle.

In the Shamburg area the sand is present but as a rule contains much water. Some gas is present, apparently localized by the small dome that results from the humping of the sand over the thick Third Sand body below.

Farther south an irregular productive area extends from Pioneer east and south about 4 miles. The sand is uniform but hard and with a permeability usually below 20 millidarcies.

In the neighborhood of Columbia Farm there is usually a bed of well-cemented pebbles at the top, and the sand is divided into two parts by a shaly zone which frequently contains pebbly beds. The upper zone is harder, less permeable, and with lower oil content.

Southeast of the productive belt the sand is usually present, but is apt to be hard and shaly. Beds of red and green shale and sandstone seem to replace the white and gray sandstone. These are more brightly colored than the red shales above the First sand, and may be the westerly edge of the Cattaraugus red facies of McKean and Warren counties.

The Second sand is perhaps the most uniform of all the sands. Its permeability is generally low, seldom being over 100 millidarcies and usually below 30 millidarcies. The oil is heavier than in the other sands, ranging from 38° to 45° A. P. I. and is dark colored. Secondary recovery by air drive has usually been successful where the permeability is not too low. Comparatively high pressures (200-300 lb. per sq. in.) are required.

In the Titusville quadrangle the Second sand is productive under about 9,600 acres. It is estimated that there are 46,240,000 barrels of oil in the sand. The average oil content in the productive areas is 240 barrels per acre-foot, of which 100 barrels per acre-foot is the greatest recovery which can be expected from intensive air drive development. Since the average thickness of sand is 20 feet there are thus about 19,200,000 barrels of recoverable oil.

The Second sand was the second productive sand encountered in the early drilling along lower Oil Creek, whence its name. East of Pleasantville the Red Valley sand is present above it, and was erroneously called the Second sand by the drillers, the true Second 50 feet below being called the Salt sand. This terminology is universal between Pleasantville and Tidioute, and was therefore followed in Bulletin 118 on the Tidioute Quadrangle (1). From Pleasantville southwest to Oil City and Franklin the lower sand is called Second sand, and since this terminology both has priority and covers a wider area, it will be given preference.

THIRD STRAY SAND

Goodwill Hill-Grand Valley pool. The Goodwill Hill-Grand Valley pool, with its outliers, covers about 7,400 acres in the northeast part of the quadrangle. Although the First sand is productive in certain areas, the greater part of the production in this district is from the Third Stray sand. Since in this area the sand is irregular, reaching 30 feet or more in thickness, in contrast to the thin and regular character of the Third Stray sand along lower Oil Creek and Pleasantville, it was considered to be the Third sand by the early drillers and is still so called. Small lenses of the true Third sand, occasionally productive, are found in places below the base of the main producing horizon and are called Fourth sand.

Essentially the pool consists of long, narrow streaks or belts of thick sand, striking N.30°E. in the north part and N.65°E. in the south part. Between the belts the sand is about half the maximum thickness in the thick parts, and becomes much more shaly, and much less permeable and productive.

Northwest of a line striking N.55°E. passing through the borough of Grand Valley the sand is thin or absent and is not reported in well records. Southeast of this line the streaks begin. They are about 60 feet thick in the thickest places east and southeast of Grand Valley, and become successively thinner to the southeast. It appears that the thickening took place partly at the bottom of the sand, so that the base of the sand descends until it joins the top of the Third (there called Fourth), giving an exaggerated thickness in some places. Where this took place it is seldom possible to distinguish the true Third sand. Due to differential compaction of the sands and shales, the top of the sand is higher over the thick belts than between them, so that the subsurface contours show small anticlinal wrinkles, which have, of course, nothing to do with structure.

East of Grand Valley there is 60 feet of this sand. The first three feet are fine to coarse white pebbly sandstone with thin beds of sandy shale. There follow 8 feet of fine, irregularly bedded and lumpy shaly sandstone. Below are 10 feet of medium-grained, rather homogeneous sandstone with scattered small quartz pebbles. Below is 12 feet of sandstone with thin shaly streaks, pebbly in certain beds. A one-foot bed of sandy shale may mark the base of the Third Stray. There follow about 20 feet of pebbly sandstone, with beds of medium to fine sandstone and sandy shale. At the base there are always a few feet of pebbly sandstone with abundant fragments of black lignitic wood. Below the base is dark gray shale with some sandy shale. The porosity averages 13 percent and the permeability is usually less than 500 millidarcies except in the coarser beds, where it may reach 2,000.

Farther southeast the sand becomes thinner and contains fewer pebbly beds and more shale. In the center of the field, where the streaks are about 40 feet thick, the sand consists of beds of fine, hard, white sandstone, with thinner beds of sandy shale, usually irregularly bedded and lumpy. Pebbles are usually present at the top and bottom, where they may be cemented tightly in a shaly matrix. The permeability ranges from 10 to 500 md., the porosity averages 15 percent and the saturation ranges from 20 to 29 percent, which is better than the average for the quadrangle. Intensive air drive has been very successful in this part of the field.

About 1,500 feet southeast of Goodwill Hill Town Hall the sand is less than 20 feet thick, and there is a narrow belt where it is comparatively unproductive. South of this point the sand thickens again, although the streaks are less pronounced. There are three or four streaks to the southeast, the last two more than 40 feet thick. Near the Enterprise-Tidioute road the sand ceases abruptly and is not recorded for several miles to the southeast.

The last two streaks constitute the Colorado pool, which is the southwestern end of the Triumph Streak. Following this streak to the northeast, it attains in the Tidioute quadrangle a thickness of more than 100 feet (1).

The Colorado pool was discovered in the summer of 1870 and was very productive, though data on initial productions are not available.

The Atlas well, located 2 miles northeast of Grand Valley, was drilled in 1867 and may be considered the discovery well of the Grand

Valley pool (9, p. 270). Other nearby wells were dry, and ten years later a new development was begun about a mile southwest of the Atlas well. This opened the northernmost of the streaks. The initial productions were not large compared to the first wells drilled in other important Third Sand pools. Small wells were brought in occasionally between Grand Valley and Colorado, but it was not until about 1890 that intensive development of the Goodwill Hill district began. In this area initial productions are said to have been several hundred barrels per day.

The total productive area of the Grand Valley-Goodwill Hill-Colorado pools embraces 7,400 acres. Measurement of the areas underlain by sands of differing thickness indicates that there are about 203,300 acre-feet of oil sand, containing 50,420,000 barrels of oil, as indicated by 90 core analyses. Assuming that the oil in excess of 150 barrels per acre-foot is recoverable by intensive air drive, there are 19,930,000 barrels of recoverable oil.

West of Grand Valley the Third Stray sand is probably present but poorly developed. Northwest of Selkirk there are several beds of sand, occasionally red, aggregating 25 or 30 feet in thickness. Some of these may belong to horizons above the Third Stray sand. One mile southeast of Cutler School a well pierced 5 feet of nonproductive sand with 5 feet of soft highly ferruginous reddish sand, 20 feet above it. At Hummer School up to 15 feet of Third Stray sand is reported. This occurrence is northwest of the line passing through Grand Valley, and is somewhat anomalous.

One mile east of Whiteoak School up to 20 feet of Third Stray sand is reported. Oil is not very abundant, and is produced along with that from the very thick Third sand below it. This thickness of pebbly sand below causes a pronounced humping in the Third Stray, which takes the shape of a dome with about 10 feet of closure. It is doubtless due to differential compaction and has no structural significance. This Third Stray sand is in the Dotyville pool.

Church Run pool. Still farther southwest, in the neighborhood of Henderson School and Henderson Church, north of Titusville, in an area of about 2,500 acres, logs of wells to the Third sand show up to 20 feet of Third Stray sand. One core from this district showed well-cemented pebbles and some shaly sandstone with a very low porosity. It is doubtful whether there is much production from this sand in this area, the bulk of the oil coming from the Third sand. It is estimated that there are 3,750,000 barrels of oil in the sand, of which less than 10 percent is recoverable.

Breedtown pool. In the same southwesterly direction, at Breedtown, there is an area of 1,160 acres where oil is produced from the Third Stray. The sand ranges from 7 to 13 feet in thickness. The sand here seems to be about 30 feet lower than would be expected, and there is a possibility that it may be the true Third sand. The logs of a few wells in the eastern part of the pool show the Third sand 33 feet below, which is about the proper interval. The westerly dip, as shown by the contours between Zerrer School and Center School, is thus partly structural and partly due to differential compaction over the thick Third Sand streak, which reaches a maximum of 60 feet one mile south of Zerrer School.

No cores were available from this pool. It is assumed that the sand contains an average of 200 barrels per acre-foot (it may be richer), which would mean a total of 2,320,000 barrels of oil, of which 580,000 are recoverable.

Pleasantville or Black Oil pool. Southeast of a NE-SW line passing through the southeast corner of the borough of Pleasantville the Third Stray sand is usually present. Its character here is very different from the Goodwill Hill pool. The sand is generally pebbly, especially at the top and bottom. Instead of occurring in streaks it is remarkably uniform in thickness, ranging between 10 and 20 feet, of which usually 8 feet is classed as pay. The texture varies considerably. Altogether, 8,645 acres have been productive, and 2,485 acres are now abandoned because of accidental water floods. Because the oil in this pool is darker than in other sands and districts, the sand is generally called the Black Oil sand. The A. P. I. gravity of the oil ranges from 44° to 50°.

In the district between Pleasantville and Shamburg a few cores show 6 to 10 feet of sand, mostly coarse, "cloverseed", with frequent pebbly beds, especially at the top and bottom. Two miles north of Pleasantville the sand is mostly coarse and pebbly, but contains shaly layers. The porosity ranges from 12 to 19 percent and the saturation is usually over 25 percent and occasionally up to 40 percent, which is high for the region. The average oil content is also high, usually over 300 barrels per acre-foot.

Wells in the district between Pleasantville and Asbury Chapel, are quickly and seriously damaged if water reaches the sand face. If the casing leaks and water accumulates in the hole, it enters the sand and nearly eliminates its permeability to oil, so that the production of the well is adversely affected. Some of the water comes back out of the sand in time, but as a rule the well is permanently damaged. Most of the wells are drilled 100 feet deeper than the sand, to make a "pocket" in which the water may collect while the casing is repaired.

Black-oil wells in this district produce no water with the oil, and it seems likely that the sand may contain less connate water than usual, so that the surface water, which may enter accidentally, encounters principally oil-wet surfaces. The permeability to water is thus quite low, but the hydrostatic head in the well forces water into the sand for several feet. On removal of the head of water in the well, however, there is no pressure in the sand to force the water out, and it remains, plugging the pores and effectually stopping the movement of the oil. It is also possible that capillary conditions in the sand are such as to cause the sand to imbibe the water, even without much hydrostatic head (26).

Repressuring with air has not been very successful in the Black Oil sand. It may be that connate water being almost lacking, the total volume of fluids in the sand is comparatively small and, therefore, the air encounters less resistance and is less effective in driving oil. Leases producing only or principally from the Black Oil sand are pumped every few days and the production per well is low but declines very slowly.

The Pleasantville pool was discovered on February 1, 1868, by the Harmonial well, in the borough of Pleasantville (267 on map). This well started with a small yield, and at the end of two weeks was pumping about 30 barrels per day. Its production gradually increased, and it finally started to flow, its best production being 125 barrels per day three months later. After other wells were drilled in the vicinity its flow ceased, and it was abandoned on November 1. (21, p. 18; 9, p. 259.) The pool was developed rapidly, but never produced more than 2,000 barrels per day, and by 1869 had begun to decline. This rapid decline was doubtless due to the thinness of the sand and its high permeability.

The central part of the Pleasantville pool is now flooded with water. The date of the beginning of the flood could not be ascertained, but it apparently was within a few years of its discovery. In 1868 casing in most wells was set with a seed-bag, but the waters from the lower Pennsylvanian sands are highly corrosive, and it is likely that the casings were eaten through, and abandoned wells were improperly plugged. The water is still advancing slowly in a southerly direction, and easterly in a lobe 1½ miles southeast of Pleasantville. A hard streak just southeast of the corner of the borough has prevented migration in a direct southeasterly direction. The watered area is shown on the map as abandoned.

Eastward from Pleasantville there is a lobe as far as Neilltown, but the sand is shaly and was never very productive. Most of this district is now abandoned. East and northeast of Tyrrel Farm School the sand is productive in isolated spots, which trend towards the Fagundus pool in the Tidioute quadrangle (1).

At Fagundus the sand is thicker, and has responded well to air drive.

Pithole pool. The Pithole pool has received a great deal of notoriety, although its total production was never very great. It was discovered on January 7, 1865, by the Frazier or United States well (282 on map) on the Holmden farm. The hole was drilled wet (i. e. without casing) and tubed to about 590 feet, or 5 feet from the top of the sand. A seed-bag packer was put on the tubing at 364½ feet. The well began to flow about 200 barrels per day with the sucker rods in the tubing, from which we may infer that it was brought in by pumping. As it was drilled with the hole full of water there would be no large show, and probably a pump was installed for testing. The sucker rods were removed in June and the flow increased to 800 barrels per day (22, p. 139).

Several factors combined to produce an unparalleled speculative boom. The industry was well established, drilling technique had advanced, and the demand for oil was growing. Oil sold for $5.00 to $8.00 per barrel. The Civil War was over, many demobilized soldiers were idle, the currency was inflated, and capitalists were eager to invest money. The Homestead well was completed in April, two more wells in June, and the four wells were producing 2,000 barrels per day by the end of June. Speculators arrived by the hundreds and half-acre leases sold as high as $16,500 (19, p. 134). In September 1865 the production of the pool was 6,000 barrels per day. Pithole is estimated to have had a population of 15,000, and had a daily newspaper, two banks, two telegraph offices, two churches, and over fifty hotels (19, p. 139), several of which were large and elegant, the Bonta House having accommodations for 175 guests (22, p. 367).

The city was short lived. In November the Frazer well ceased flowing. In January 1866 the production had declined to 3,600 barrels, and in 1867 it was less than 1,000 barrels per day. In 1867 the average price per barrel was $2.50. It is stated that 3,500,000 barrels were produced from less than 100 acres (19, p. 140). As the sand on the Morey and Holmden farms is less than 15 feet thick, this figure is quite impossible. The old pool, as outlined by tradition, is shown on the map as an abandoned area, and embraces about 250 acres. Assuming a porosity of 20 percent, an initial oil saturation of 70 percent, and a final saturation of 30 percent, about 620 barrels per acre-foot could be produced. Over 250 acres with 15 feet of sand this would be about 2,000,000 barrels of oil. This figure agrees roughly with the sum of the estimates of daily production, and is an outside estimate of the oil that was produced from the pool.

The field and city were almost deserted by 1869, and the main part of the pool is now flooded. A few wells drilled in 1923 on the Morey farm on the northwest edge of the old pool showed 2 to 13 feet of sand. The southeasternmost well drilled into water. The flood may have started shortly after the collapse of the boom, but there are no statements that the sharp decline in production was due to a water flood. The reasons for the rapid decline are obvious. There were only 10 to 15 feet of highly permeable, coarse sand, and the wells were spaced absurdly close. All the gas and most of the oil were withdrawn in less than a year after the discovery. It would probably be feasible to unwater the pool as Triumph and Church Run have been unwatered, but it is questionable whether enough oil remains to make it worth while. Carll states (9, p. 296) that several small pools containing a large amount of oil were discovered on the edges of the Pithole field after the central district was flooded. Obviously they were traps into which the water had forced the oil, and when tapped, the water encroached rapidly. A well drilled on the Hyner farm about 1920 produced for a time. It was not ascertained whether it flooded out.

North of the Pithole pool proper there is a considerable area where the Third Stray sand is productive, although most of the production comes from the Red Valley and Second sands. The sand averages 8 feet thick and is pebbly and coarse but contains some shale and has rather low permeability.

The old Cashup pool 1½ miles northeast of Pithole was discovered in 1871 and one well flowed 1,000 barrels per day. The sand is probably similar to the sand in the Pithole pool, and a recent core showed 14 feet of coarse and pebbly sand with a permeability up to 800 md. This pool was never flooded, and embraced 270 acres, about half of which is now abandoned.

Shamburg-Pioneer. From south of Shamburg to Pioneer the Third Stray sand is present, but thin and not very productive. It is also present east and south of Russell Corners, where it is partly flooded. The sand is also present at Columbia Farm and north of Oakland Church. It is thin and not very productive in these districts.

Nomenclature of Third Stray sand. As shown in table 1 (p. 7) and mentioned in the foregoing descriptions of the pools, various names have been applied to the Third Stray sand. In the report on the Tidioute quadrangle (1) this sand was called the Third, but it was recognized that it was not the Third sand of Oil Creek.

In the northeast portion of the Titusville quadrangle usage is the same as in the Tidioute quadrangle, and the sand is called the Third. At Pleasantville and south to Pithole the sand is called the Black-oil sand. Along Oil Creek and in the southwest portion of the quadrangle it is called the Gray sand. North of Titusville in the Church Run district it is variously called the Gray, Stray, and Second.

The early name of "Stray Third" has dropped out of general usage, but the sand was accurately described and correlated by Carll (10) under this name in 1875. None of the names used in the quadrangle has more than local application except "Gray," which is also used in the Oil City and Franklin quadrangles. This word implies color, however, and is not appropriate. Since the term "Third Stray" is well established in the literature it has been used to describe the sand in this report.

THIRD SAND

Church Run pool. The Church Run pool is a long narrow body of sand which extends northward from Titusville. It has been traced into the Corry quadrangle to a point three miles east of Spartansburg, or thirteen miles north of Titusville, making the total length of the sand body nearly twenty miles.

The Church Run pool proper is along both sides of Church Run, north of the city of Titusville, where it is about two miles wide. West of a north-south line passing through the center of the city the sand is very thin, fine, and shaly, and rarely productive. A few wells, now abandoned, produced oil on Thompson Run about a mile above Hydetown, but these are the only wells that have produced oil from the Third sand west of this line. Eastward the sand thickens rapidly, attaining 50 feet and more within one-third mile from the edge. It is mostly pebbly throughout its entire thickness, some beds being loose unconsolidated conglomerate with pebbles up to one inch. In places, however, it contains beds of sandstone without pebbles, and a few beds of shale. The permeability is very high, amounting to 2,000-5,000 millidarcies in the loose conglomerates. To the east the pebbles disappear and the sand becomes thinner, consisting of medium to fine-grained white sandstone with beds of shale and sandy shale. Some sand beds are rather massive, and some contain numerous irregular, very thin dark shale partings. The permeability decreases to between 10 and 50 millidarcies.

The sand divides into two lobes about two miles northeast of Titusville. Cores are not available from this region.

The pebbly western edge continues straight north from Titusville for 2½ miles. It then bears to the northeast for 1½ miles, regaining its northerly direction at Kerr School. The productive belt is less than a mile wide. Continuing to the north the sand is about 30 feet thick near its western edge, and is usually less than a mile wide. A core from near Hummer School showed 27 feet of sand, with a pebbly bed at the top. The first 12 feet consists of sandstone with numerous clay partings and fragments. The sand may be more pebbly to the west.

The Church Run pool was discovered by the Eureka well. According to Carll (21, p. 66) it was located 1½ miles northeast of Titusville in the valley of Church Run, and encountered 70 feet of very coarse sand with pebbles, from 504 to 574 feet. It was drilled in November 1865, and at first produced about 52 barrels per day. Production dropped to 7½ barrels per day by May 1868. The well was then cleaned out and shot, and for some days produced 175 barrels per day. It had to be shot every six weeks to keep up the production. Although not so stated by Carll, this was doubtless to melt and shake off the paraffin which deposited on the face of the sand.

At some time after the original drilling, surface water entered the sand through improperly cased wells, and flooded the western, pebbly part of the Church Run pool. It was abandoned for many years. About 1920-22, attempts were made to pump the water off. The water was quite fresh and filled the holes to the surface in the southern part of the pool and to about 300 feet from the surface in the northern part of the pool. Many months of pumping were required before appreciable quantities of oil were obtained. Since then the field has been entirely unwatered and has produced largely. Two leases are still operated under vacuum, but the majority are being operated under air and gas drive.

The flood never extended eastward into the finer-grained portion of the sand. At about the time the pool was being unwatered, several wells were drilled near the eastern limit of the flood and produced as much as 150 barrels per day for a short time. They undoubtedly encountered oil which had been collected and trapped by the advancing flood.

Dotyville pool. About a mile northwest of Dotyville there is a peculiar isolated body of thick Third sand. It is about 1½ miles long and 1,500 feet wide, embraces 160 acres, and lies 1 mile east of the edge of the Church Run pool. The sand attains a thickness of 80 feet and is reported to be almost entirely pebbly. No cores are available. The eastern edge of production has been outlined by dry holes and is very irregular, some dry holes being completely surrounded by producing wells. The Third Stray is present in this area and is reported in a few well records. Over the thick part of the sand it shows a dome 20 feet high. In two small outliers the Third and Third Stray sands are present but thin and not very productive.

The Dotyville pool was discovered by the Newton gas well (26 on map), which was drilled in May 1872 and is estimated to have produced

5,000,000 cubic feet per day (21, p. 198). In the fall of 1875 the well started to make salt water, which interfered with the flow of gas. It was tubed and pumped, and in addition to water made a little oil. Shortly after its completion, pipe lines were laid to Titusville, and provided considerable quantities of gas for industrial and domestic consumption until about 1876.

In recent years the pool has been subjected to vacuum and in addition to the oil has produced considerable quantities of casing-head gasoline. There apparently was a large amount of connate water, but its original and present location could not be ascertained. One well pumped nothing but salt water for six years, finally making 8 barrels of oil per day.

Watson Flats. Watson Flats are the flood plains of Oil and Pine Creeks east of Titusville. The Third sand here is continuous with the Church Run pool to the north and the Octave pool to the south, but an area of 530 acres is here discussed separately.

Cores show the sand to be 50 feet thick near its western edge and 30 feet thick at East Titusville. To the west the upper part of the sand is pebbly, and the middle and lower parts medium to coarse, with a permeability of 30 to 50 millidarcies. Usually a bed of pebbles occurs at the base. To the east the pebble beds occur only at the top and base, while the sand in the middle is fine, hard, and interbedded with shale.

This district includes the Drake well, which encountered oil in a stray sand at a depth of 69 feet in August 1859. It seems likely that the Third sand was first penetrated during the summer of 1860 at McClintockville and at Tidioute, and the Third sand on Watson Flats may not have been discovered until late 1860 or 1861. The flats were drilled extensively during 1861. These early wells were abandoned without making any effort to protect the sand from surface water, and by 1869 few were still producing (21, p. 69).

The district has been redrilled in recent years, and in 1940 a modern air drive program is operating on a lease half a mile north of the Drake well.

Octave pool. From Watson Flats the sand bears in a southwesterly direction and becomes markedly streaked and lobate. Between Zerrer School and Boughton there are four main thick streaks, separated by unproductive belts. The sand reaches a maximum thickness of 60 feet and is characteristically pebbly in the thicker places. Where the sand is thinner the middle part is likely to be medium to coarse-grained, with occasional shaly beds, and with a permeability usually less than 100 millidarcies.

The easternmost streak, between Boughton and Redfield School, is 15 to 20 feet thick, and the pebbles are confined to the top and base. The central part of the sand is alternating sandstone and shaly sandstone with a permeability of less than 50 millidarcies.

The two easternmost streaks pinch out to the north, i. e., up-dip, and originally produced large quantities of gas half a mile south of Fieldmore Springs.

The Octave pool is productive over about 1,360 acres, and is estimated to contain 13,165,000 barrels of oil, of which 4,937,000 are recoverable. The thicker parts of the pool have been operated mostly with vacuum, but during recent years an air drive project has been successful, in spite of difficulties owing to the presence of certain exceedingly permeable beds.

Miller Farm. At Miller Farm an isolated thick body of Third sand underlies about 50 acres. No cores are available, but it is reported that as much as 75 feet of hard, blue, shaly sandstone was quite productive. It may be that the entire thickness of the Third Sand formation has become sandy, or it may be that there is here another thick lens like the one in the Dotyville pool. It lies between the Third Sand bodies of Octave and Shamburg, but is apparently not connected to either.

Cherrytree pool. South of the Octave pool the Third sand continues southwest and south to a point 1 mile northeast of Cherrytree. The body of sand is only ½ mile wide and from 20 to 30 feet thick. The Cherrytree pool is separated from the Octave pool by a space about half a mile wide north of Toonerville where the sand is flooded by water.

In the Cherrytree pool pebbles are scattered in sandstone or shaly sandstone in the upper and lower parts of the sand. The main body of the sand consists of fine- to medium-grained sandstone with abundant thin shaly partings, often very irregular, and with small lumps and balls of shale. Certain beds are very shaly and probably unproductive. The permeability is usually less than 100 millidarcies. Recent application of air drive has been successful. The pool contains 820 acres.

Shamburg pool. The Shamburg pool roughly parallels the Octave pool, lying 3½ miles to the southeast. It is wider and the sand is thicker in the southern part.

South of Shamburg Corners there are three streaks of sand, all of them consisting of rather fine, hard sand, in places shaly, with rather low permeability. North of Shamburg Corners the sand is thick and soft, and contains numerous pebbly beds, especially in the upper part. The pebbly zone seems to have a northwest-southeast trend, continuing southeast almost to West Pithole Creek. A narrow belt of shaly, impervious sand, striking NW-SE, passes about half a mile north of Shamburg Corners, and north of it the pebbles are lacking, and the sand is much thinner and soft and sugary. A very slow water-flood has been encroaching in this area for many years; its approximate extent is shown by the area on the map marked as abandoned.

The Third sand belt extends about 5 miles farther northeast, and passes west of Pleasantville, the sand becoming thinner and narrower. It becomes quite fine-grained, hard, and less permeable, but is productive as far as Enterprise. In the neighborhood of Pleasantville the sand contains some gas.

The Shamburg pool was discovered by the Shamburg well which commenced producing February 19, 1866. The field was developed slowly, and in 1869 was producing 1,200 to 1,400 barrels per day (22, p. 459). Several wells are reported to have flowed 400 barrels per day when first brought in. The Jack Brown well on the Atkinson farm produced 65,917 barrels from December 27, 1867 to August 17, 1868, an average of 284 barrels per day.

The use of suction is said to have been attempted to stimulate production in this field very early in its life. During the 1920s suction was extensively applied, and large quantities of natural gasoline were manufactured. In 1940 most of the pool is under air drive.

Small areas to the east of the Shamburg pool have up to 20 feet of Third sand, and small quantities of oil are produced from the Third Sand along with oil from the Red Valley, Second, and Third Stray.

In the Shamburg pool and the outlying fields there are 4,885 acres with an estimated total content of 25,500,000 barrels of oil, of which about 9,400,000 may be recoverable.

Enterprise. North of Enterprise the Third sand is thin but has been productive. Three small pools containing about 260 acres are in operation. The northernmost, east of Mt. Hope School, produces only gas from the Third sand. Between Enterprise and Cheney Cemetery the Third sand becomes valueless and the Third Stray above becomes productive. The leases in this district are partly abandoned, and it was impossible to determine the exact limits of each sand.

Goodwill Hill-Grand Valley. Throughout the Goodwill Hill-Grand Valley district the Third sand is generally present as 5 to 20 feet of hard white sandstone, usually shaly and unproductive. In some places it is productive of oil and is called the Fourth Sand. Near Selkirk it is pebbly. In the extreme northern part of the quadrangle, north of Starr, is an irregular small pool of productive Third sand. It was discovered about 1880 or 1890, but a westward extension was found in 1938. It contains about 100 acres altogether.

In the Goodwill Hill-Grand Valley district the Third sand has a productive area of about 1,200 acres, and is estimated to contain 2,500,000 barrels of oil, of which about 700,000 may be recoverable.

Pioneer-Petroleum Center. Lying south of the southern tips of the Cherrytree and Shamburg pools are the Pioneer and Petroleum Center pools. The sand is streaked and lobate. The thick places consist mostly of pebbly sand. At Pioneer, on both sides of Oil Creek, the sand is nearly all coarse pebble. Near the margins the pebbles disappear from the lower and middle parts of the sand, and the sand is sugary with moderate to low permeability. The thick streaks bear east to northeast.

Just north of Petroleum Center there is a belt half a mile wide where the sand is about 20 feet thick and is hard, shaly, and comparatively unproductive. South of it the sand at Columbia Farm is again 30 to 50 feet thick and is characteristically pebbly. In some places the pebbles are restricted to certain horizons. The average porosity ranges from 11 to 16 percent and the permeability is variable. The Pioneer streak swings south, passing east of Kaneville, and appears to join the Petroleum Center streak at Columbia Farm.

The first large flowing wells were completed in the spring of 1861 along lower Oil Creek. Drilling was continued up the stream, and during late 1861 and early 1862 a large number of prolific wells were drilled at Petroleum Center and Pioneer. Among these the Empire well was completed in September 1861, with a flowing production of 3,000 barrels which completely broke the market. The Noble well was drilled in January 1863, and flowed until February 28, 1865, and is estimated to have produced 1,000,000 barrels of oil. It was not until 1865 that it became generally realized that oil is not necessarily found only along the watercourses, and the prolific wells on the hills three-quarters of a mile northwest of Petroleum Center drilled in 1865 conclusively proved that oil can be found under higher land as well.

South of Petroleum Center, the Story Farm, later called Columbia Farm, was drilled in 1861 to 1865 and was very productive.

The Petroleum Center pool was partly flooded with surface water about 1880. About 1920 it was unwatered, and for a time it was operated under suction, the gas, after the gasoline had been removed, being returned to the sand. Since about 1931 it has been under air drive, and an intensive program has been operating successfully at Columbia Farm.

OIL PRODUCTION

By Parke A. Dickey and Robert B. Bossler

HISTORICAL SKETCH

Any complete discussion of the history of the early oil industry would be out of place in this report. The reader is referred to a recent and authoritative work by Paul H. Giddens covering the development of the oil industry from the early days to about 1870. A bibliography will be found in that book (19). The most useful book to a petroleum engineer is ''Petrolia'', by Andrew Cone and Walter R. Johns (22), since it gives an individual description of each farm, with data on the number of wells, their depths, initial and subsequent production, etc. The reports of the Second Geological Survey of Pennsylvania, especially those by John F. Carll, laid the foundations of petroleum geology and engineering. The following discussion is based largely on the works of Giddens and Carll.

The early French explorers noted the presence of oil in what is now western New York, and the first recorded reference is by the Franciscan missionary, Joseph de la Roche d'Allion, in 1627. The earliest reference to oil in northwestern Pennsylvania is by David Zeisberger, who reported collecting oil from ''wells'' in 1768, while camped along the Allegheny River at Tionesta.

The early explorers and settlers found groups of pits, notably on Oil Creek below Titusville, but also at other localities, where oil seeps were known to exist. There can be little doubt that they were dug for collecting oil, since they were 6 to 10 feet deep and cribbed with timber, but by whom is a mystery. The Seneca Indians in the region in the 17th century knew nothing of the origin of the pits, and it is probable that they were dug by an earlier tribe, possibly also of Iroquois stock. These pits may still be seen along Oil Creek about a mile below Titusville, and along Hosmer Run, west of Garland, Pa.

The Senecas did, however, collect small quantities of oil for medicinal purposes, and the white settlers continued its collection and use. Nathan Carey is reported to have shipped ''Seneca Oil'' to Pittsburgh in 1790 in five-gallon kegs slung over a horse's back. It was used mostly as a medicine, largely for external application, but was also taken internally. Its possibilities as an illuminant and lubricant were early recognized, but the lack of knowledge of how to refine it, and any suitable lamp, deterred its general use for these purposes.

During the 1850s, first in England and then in the United States, kerosene or oil distilled from coal came into general use as an illuminating oil. By 1859 it is estimated that $4,000,000 was invested in this industry in the United States. Samuel Kier, of Pittsburgh, who had been a principal marketer of petroleum produced by salt wells near Tarentum, Pa., and J. C. Booth, a Philadelphia chemist, developed a method of making kerosene from petroleum, and also devised an improved lamp about 1850. A. C. Ferris improved the color and odor of petroleum kerosene, and sold about 1,180 barrels in New York in 1859, most of which came from Tarentum.

Dr. Francis Brewer, a Titusville physician and graduate of Dartmouth College, took some specimens from the Titusville seeps to Dartmouth for analysis. Another alumnus, George H. Bissell, became interested in the possibilities of the material, and with Jonathan G. Eveleth, formed the Pennsylvania Rock Oil Company in New York on Dec. 30, 1854. Attempts to sell stock were largely unsuccessful. On April 6, 1855, Professor Benjamin Silliman, the noted chemist and mineralogist of Yale University, submitted a complete analysis and glowing report on the possible uses of petroleum, especially as an illuminant. There seemed to be a better chance to sell stock if the company were incorporated in Connecticut, and most of the promoters were residents of New Haven, so a new Pennsylvania Rock Oil Company was organized in that city. The stock sold rapidly, but disagreements and other difficulties developed. James M. Townsend, a New Haven banker and then president of the company, sent Edwin L. Drake, a friend of his who was a railroad conductor, to examine the properties the company had leased at Titusville, in 1857. Drake also visited the salt wells at Tarentum, and returned to New Haven fired with enthusiasm and convinced that oil could best be secured by drilling. The company was reorganized on March 23, 1858, as The Seneca Oil Company, with a capitalization of $300,000.

Drake came to Titusville in May 1858. He proceeded to collect oil from the springs and attempted to dig a well. This not proving promising, he purchased a boiler, engines, and lumber for a derrick, but had difficulty in securing a driller. He finally hired William A. Smith of Salina, a blacksmith who had made tools for the Tarentum salt wells, and who started work in May 1859. Having tried unsuccessfully to dig and crib a hole to bed rock, they drove 32 feet of cast iron pipe and began to drill. On Saturday, August 27, at a depth of 69½ feet, work was suspended, and on Sunday afternoon, the driller noted that oil had risen into the well to within a few feet from the surface. The well produced about 10 barrels a day. Later, when the well was tubed and pumped from the bottom it produced about 25 barrels a day.

This discovery of oil in larger quantities than had ever been secured before caused immediate excitement. Land all the way down Oil Creek and even up the Allegheny River was quickly leased. The second well was drilled by William Barnsdall and Boone Meade of Titusville, a short distance north of the Drake well, and it flowed 10 barrels a day at 122 feet, probably from the First sand. Brewer, Watson and Company completed a well on the McClintock farm near Rouseville in November 1859.

By the summer of 1860 a boom was well under way, and by the end of the year 74 producing wells had been drilled along Oil Creek and the Allegheny River from Tidioute to Franklin.

In April 1861, a well on the Buchanan farm at Rouseville came in, flowing 3,000 barrels per day. It caught fire and nineteen persons were fatally burned. Numerous other flowing wells were brought in during 1861 and 1862.

During the 1870s and 1880s the attention of the operators was diverted to the new, flush fields of the eastern district, especially Bradford, and there was little development work in the Titusville district. Surface water flooded several pools, notably Petroleum Center, Church Run, and Pleasantville.

About 1890 there was renewed drilling in some fields. From 1918 to 1925 the high price of oil caused renewed development, and vacuum and natural gasoline plants were installed on many leases. The pebbly sands in particular yielded large quantities of natural gasoline.

About 1920 the method of injecting air or gas became common, and especially from 1930 to 1940 there was a good deal of development work by air drive.

EARLY DRILLING TECHNIQUE

The first well drilled in the United States with anything approaching modern technique was put down for salt water by the Ruffner Brothers in 1808 on the Great Kanawha River in West Virginia. The tools and method of drilling were developed in that district during the first quarter of the 19th century, and it was reported that salt wells along the Little Muskingum River were commonly drilled to depths of 400 and 500 feet in 1826.

In 1861 oil wells were usually started with a wooden conductor pipe to keep out the loose soil, or cast iron drive pipe where there was deep clay or gravel. A 4-inch hole was drilled through the solid rock, which stayed full of water from the surface and upper sands. When the oil horizon was penetrated, tubing was set in the well to the bottom, with the working barrel of the pump attached to its lower end. At a point below the source of the water, a seed-bag packer was placed. This was a leather sleeve on the outside of the tubing, tied at both ends. Flax seed was stuffed between the leather and the pipe so that when the tubing was run into the well the water would cause the seed to swell and engage the wall of the hole. The remainder of the pump assembly was attached to wooden sucker rods and run inside the tubing. After allowing time for the flax seed to swell, the water in the hole was pumped out, and if the well was a producer, oil commenced to flow into the hole. The seed bag kept the surface water out.

By this method, it was not possible to remove the tubing without letting water into the well. By 1868 heavier machinery was in common use, and it was customary to drill a 5½-inch hole. Casing of 3¼ inches inside diameter was run, and the seed-bag packer placed at the lower end of this casing. It was then possible to withdraw the 2¾-inch outside diameter tubing without disturbing the packer.

Both these methods were called "wet hole" drilling, since the hole was full of water until tubing was run and the well pumped. Consequently, oil shows were rarely encountered while drilling. About 1875 it became customary to use 8-inch drive pipe, and to carry an 8-inch hole below the water-bearing strata. The size of the hole was then reduced to 5½ inches, and 5⅝-inch casing was set on the shoulder thus made. This resulted in an effective water shut-off, and is the method still in use.

Until about 1900 all wells were drilled by steam power with a standard cable-tool rig, including a 60- or 80-foot wooden derrick.

Colonel E. A. Roberts invented the oil-well torpedo and applied for a patent in 1864. In January 1865, its first test in a well on Watson Flats was highly successful, but most operators were fearful of ruining their wells, and it was not until January 1867, when a dry hole was transformed to a good producer by shooting, that the method came into general use.

PRESENT DRILLING AND PUMPING TECHNIQUE

At the present time, nearly all wells are drilled with a semi-portable machine of the Star or Keystone type, using a gasoline engine as the prime mover. Up to 40 feet of wooden conductor is set at the surface, or in glacial-filled valleys as much as 300 feet of drive pipe is used. Surface casing, 6¼ inches in diameter, is usually set below the Corry sandstone at an average depth of 250 feet. In some areas it is necessary to case below the First sand. A 6-inch hole is drilled 20 to 40 feet below the base of the lowest producing sand. The well is shot with two to four quarts of nitroglycerine per foot tamped with water. After cleaning out the debris from the shot, 2-inch tubing is run and the working barrel is usually set below the producing sand. Wooden sucker rods 20-25 feet long and about an inch in diameter, with wrought iron couplings, were formerly used, but standard iron rods are mostly used at present. Liner is very seldom used, and the holes stand open from the casing shoe down.

Formerly much trouble was experienced with paraffin collecting on the walls of the hole and in the tubing, but the production per well is now so low that it is not a problem. In certain districts calcium carbonate (usually and erroneously called ''gypsum'') is deposited on the face of the sand. This was particularly troublesome when suction was in general use, since the water released carbon-dioxide on reaching the hole, and its calcium content changed from the soluble bicarbonate to the insoluble carbonate. With the use of compressed air drive this trouble has disappeared, since air oxidizes the oil to such an extent that it contains large quantities of carbon dioxide which dissolves in the water and retains the calcium in solution.

Pumping is usually by means of central power operated by a gas engine burning the gas produced with the oil. The gas is collected by gathering lines attached to the casing head. Most of the powers are of the geared type with one or two eccentrics. The usual types of shackle or rod lines are used to connect the wells to the power. The pump jacks are usually home-made, of the Oklahoma pattern, and are set on wooden sills. Most leases are pumped two or three times a week.

NATURAL PRODUCTION

Complete figures are not available for the original flush production of any of the leases in the Titusville quadrangle. The initial production of some of the districts has been given in a previous section.

Production figures are available for certain leases from about 1900 on. New wells in only slightly developed territory had initial productions of 10 to 50 barrels per day, and averaged as much as one barrel per day for a year or more. At the present time, most old wells not under secondary recovery produce less than one-quarter barrel per day, and the average is probably less than one-tenth barrel per day.

VACUUM

From 1918 to 1925, when the use of suction was prevalent, four to ten gallons of gasoline were recovered per thousand cubic feet of gas by the compression process. Oil production was stimulated only slightly by vacuum, and for a comparatively short time. Suction removed most of the remaining gas in the oil sands, and by removing the lighter hydrocarbons, decreased the A. P. I. gravity and increased the viscosity of the oil, so that it undoubtedly left the oil more difficult to recover. On the other hand, prices for natural gasoline were as high as 20 cents per gallon, and the profit from its manufacture may have been sufficient to offset the probable loss in ultimate recovery of oil.

WATER FLOODING

The remarkable success in increasing the recovery of oil in the Bradford district by artificial flooding with water led to many attempts to employ the method in the Titusville district. During the early accidental water floods, sharp increases in production were noted before the water entered the wells (9, p. 269). However, no case where water was artificially introduced resulted in any increase in oil production. Some attempts were made by the haphazard method of permitting surface water to enter, but at least three employed the best technique in use at Bradford: a five-spot pattern was used, the sand was cored, packers properly set, and pressure applied at the surface. In most cases the producing wells simply increased their production of water with no increase in oil.

The reasons for the total failure of water-flooding attempts in this district are not clear. Two explanations have been advanced. In the first place, the Venango sands show greater variations in permeability than the Bradford sands. The water passes only through the more permeable beds, which are already more nearly emptied of their oil than the other beds. In the second place, the oil content of the sand is about 30 percent and the connate water content about 40 percent of the pore space. It may well be that the introduction of water into a sand with this oil-water ratio will result in the movement of water only (27).

AIR AND GAS DRIVE

Since about 1920 secondary recovery by air or gas drive, usually called repressuring, has become common practice throughout most of the Titusville quadrangle. In most districts, considerable increases in recovery have been obtained by this method.

The first recorded attempts to repressure oil sands were made by Mark B. Mitchell at Franklin, Pa., in the early years of the present century. A patent on the method was applied for August 4, 1904, and granted July 10, 1906 (U. S. Patent 825,745). The method was first used on a commercial scale by I. L. Dunn near Chester Hill, Ohio, in 1911. Rights for the use of the process were acquired by the Brundred Oil Company, of Oil City, Pa., in 1914. The patents were later declared invalid.

The method was first successful in Pennsylvania on a property at Hamilton Corners, near Oil City (17, 23) in 1916, and since then it has been in continuous application there. The oil production of this property is shown in Figure 8. The method did not become widespread in the district until about 1927.

At present the common practice is to introduce air into specially drilled air-intake wells. These wells are cored in the sand, and the samples analyzed for permeability, porosity, oil and water content. If, as is usually the case, the permeability shows wide variations, the sand is segregated into two to five parts, and packers are set so that the air can be injected into the different sand sections under different pressures. A manifold with separate orifice-meter connections is installed at the well heads, and gauge valves adjusted so that about 1,000 cubic feet of air will be injected per day per vertical foot of sand. Pressures necessary to inject this quantity of air range from 50 to 400 pounds per square inch. There is occasionally a ''breakdown pressure'', or critical pressure, below which little or no air enters the sand, and above which the volume of air entering is a direct function of the pressure.

In general, pressure wells are located with respect to old oil wells so that as symmetrical well-spacing pattern as possible will be obtained. This results, at best, in irregular patterns and wide variations in spacing. More recent intensive development programs have been based on uniform ''seven-spot'' patterns, both new intake and output wells being drilled with spacings of 150 to 250 feet (0.67 to 1.85 acres per oil well and 1.34 to 3.70 acres per air well).

Compressor plants range from small makeshift outfits to large two-stage compressors with capacity up to 1,000,000 cubic feet per day at pressures up to 400 pounds per square inch.

The mixture of air and gas collected from the casing heads is used for fuel, and the surplus is returned to the sand. In order to avoid mixing the surplus with the compressed air it is usually handled only during certain hours, or by a separate compressor. On some leases the gas from the wells is 50 to 75 percent combustible; on others it is almost pure air.

A recent study (24) indicates that by the air-drive method from 10 to more than 100 barrels of oil per acre-foot can be recovered. Most of this oil would have been unrecoverable by natural production, since the rate of entry of the oil into the wells would be so slow that it would not pay to operate them.

This oil will probably be recovered in from 10 to 40 years, but one-half of it will be recovered during the first third of the operating period. The speed of recovery, doubtless, depends on the spacing of the wells, but with the data available, no relation could be worked out. During the life, to date, of a number of repressuring projects, the ratio of air injected to oil recovered ranges between 6 and 22 thousand cubic feet per barrel of oil produced.

Oil recovery from typical leases. Production-decline curves of six leases in the Titusville quadrangle, shown in figures 5 to 10, illustrate the increased recovery obtained by the air- and gas-drive method.

The average yearly production, expressed as barrels per well per month for Lease VII, is shown in Figure 5. This lease has an area of 133 acres, and from 1929 on had 62 oil wells and 13 input wells. Air and mixed air-gas is injected into a total of about 35 feet of sand (Second and Third). The average oil content of the sand was 275 barrels per acre-foot.

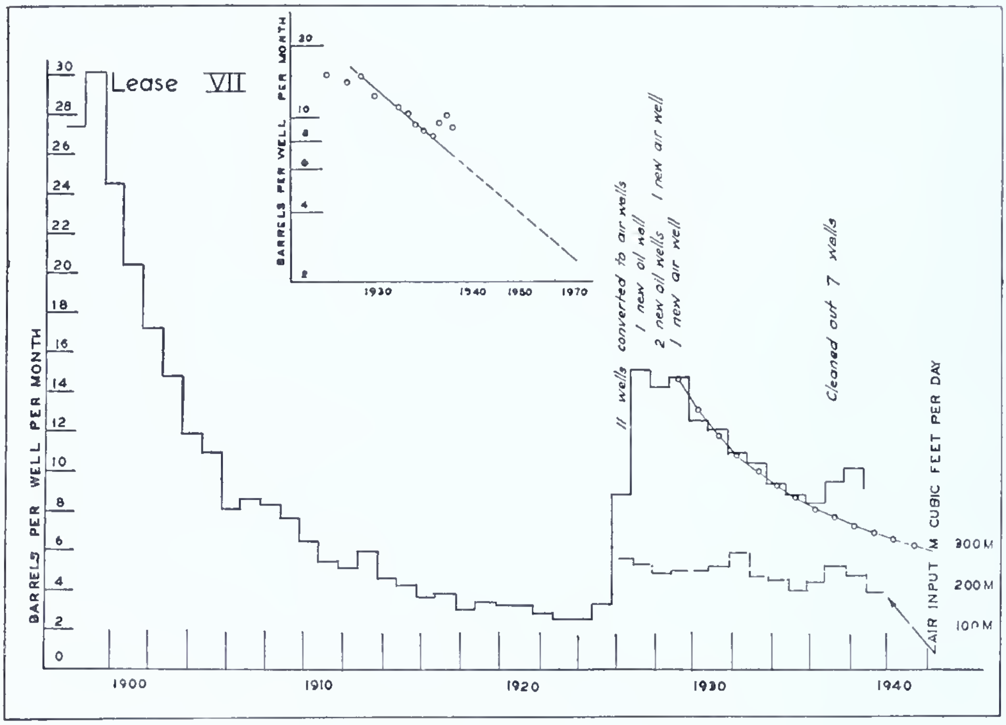

Figure 5. Production-decline curve, Lease VII

From 1898 to 1925 this lease produced about 150,000 barrels of oil, or about 1,128 barrels per acre. In 1926 air repressuring was begun, and from 1926 to 1939 it produced 114,200 barrels, or an additional 859 barrels per acre. During that time 1,254,505,000 cubic feet of air were injected at about 310 pounds pressure, so that about 11,000 cubic feet were injected per barrel of oil recovered. If the production-decline curve since 1926 is extended into the future, and no new wells are drilled, the oil wells will be producing less than three barrels per month each in 1968. By that time the lease will have produced an additional 92,000 barrels, so that with the present well spacing of 2.14 acres per oil well and 10.2 acres per air well (whose geometric average is 4.66) the lease will have recovered, by means of air drive, 206,200 barrels of oil, or 44 barrels per acre-foot.

Lease III (Fig. 6) is in considerably poorer territory. Ten new wells were drilled in 1904, and production that year reached as much

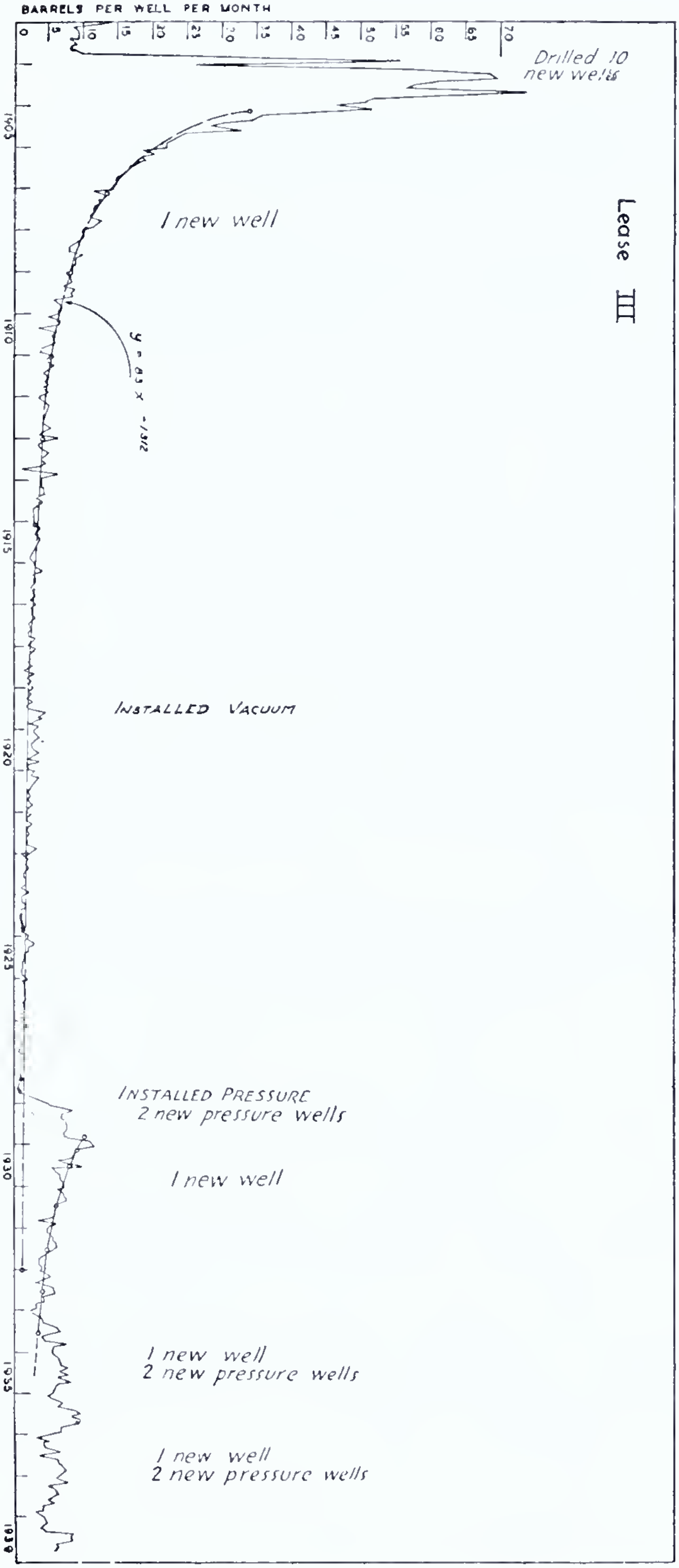

Figure 6. Production-decline curve, Lease III

as 70 barrels per well per month. It declined rapidly, and by 1907 the wells were producing about 12 barrels per well per month. The production from 1905 to 1919 follows almost exactly the graph of the equation.

$$y = 83x^{-1.312}$$

Vacuum was installed in 1919. Production was increased slightly, but by 1924 had fallen below what it should have been according to the equation.

Two new pressure wells and one new oil well were drilled between 1928 and 1930, which materially increased the production. It fell, however, to about 3 barrels per well per month by 1934. During this period the lease produced about 6,000 barrels of oil. It had an area of 35 acres with 3 air wells and 17 oil wells. The sand is 20 feet thick and has an estimated oil content of 210 barrels per acre-foot. New wells were drilled in 1935 and 1937 which offset the decline in production.

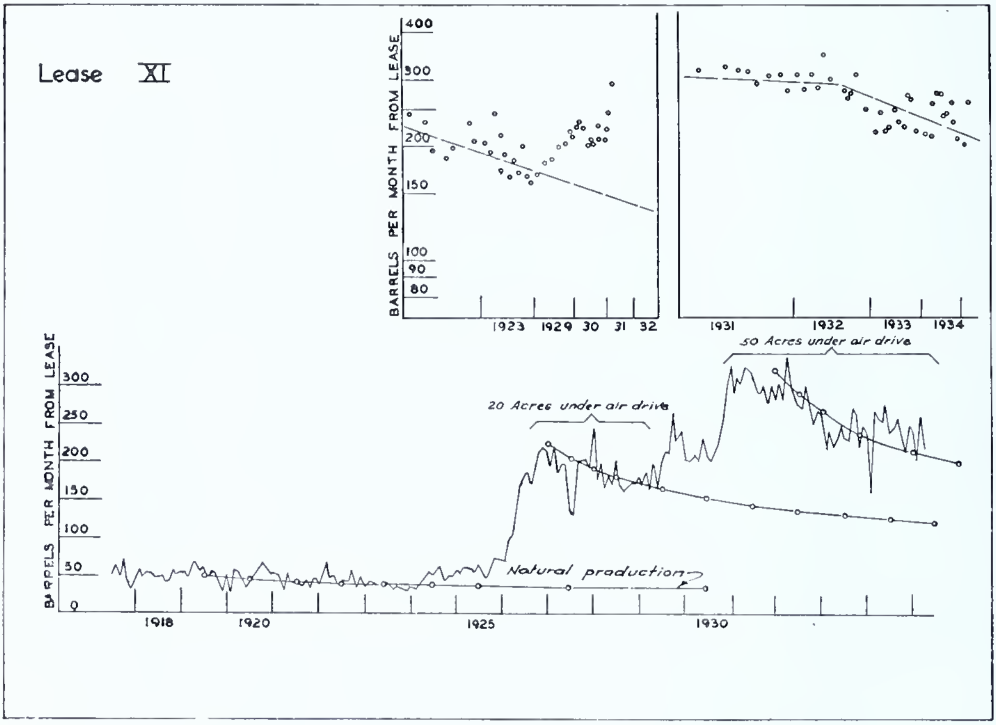

Figure 7. Production-decline curve, Lease XI

On lease XI (Fig. 7) there were two periods of development. In 1925 and 1926, 20 acres were placed under air drive, and the development was extended to cover 50 acres in 1929 and 1930. Both decline curves, which are plotted logarithmically in the upper part of the figure, indicate that the cumulative ultimate recovery will be about 1,500 barrels per acre from about 20 feet of sand.

Lease V is the property at Hamilton Corners on which air was first applied in Pennsylvania. No new development was done between 1926 and 1939. During that time the production declined logarithmically, except for a period from 1932 to 1934 when the air input was not kept up to normal. The well spacing on this lease was wide and irregular.

Lease VIII is a property of 61 acres underlain by 24 feet of Second sand, with an estimated oil content of 325 barrels per acre-foot. Air and gas pressure was applied experimentally in 1926 and 1927, and applied over the lease in 1929 and 1930. There were 32 oil wells and 10 air wells (one of which was on the boundary) from 1930 to 1935. The production declined rather rapidly, and about 49,000 barrels were produced from 1928 through 1939. It is estimated that 27,000 barrels more will be produced before 1951. Some of this oil was produced by wells outside the area affected by air, and it is estimated that the cumulative ultimate recovery due to air drive will not exceed 1,100 barrels per acre. The wells are widely spaced and not laid out in a regular pattern. If they had been closely and properly spaced it is likely that much more oil would have been recovered in a shorter period of time.

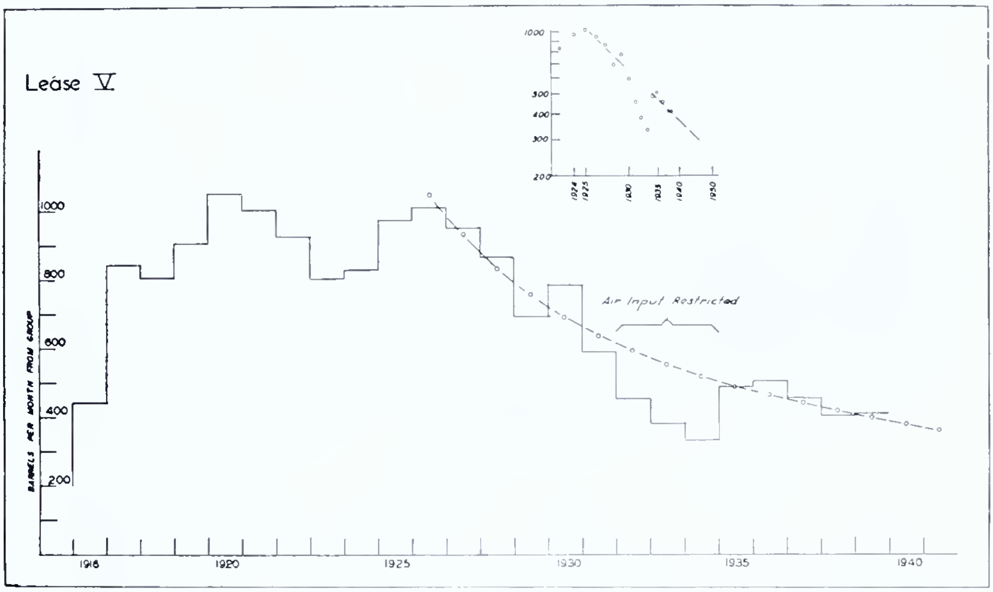

Figure 8. Production-decline curve, Lease V

Several leases in the district have been developed by spacing wells closely on a regular "seven-spot" pattern. In a pattern of this type the oil wells are located at the corners of hexagons, and air wells at their centers. In a complete pattern of this type there are twice as many oil wells as air wells. Each air well drives towards six oil wells, and each oil well receives air from three air wells. Spacings range from 150 to 300 feet. It seems likely that these developments will recover considerably more oil in less time than the older haphazard method of drilling a few air wells between old oil wells. It was impossible to estimate accurately the cumulative ultimate recovery of any of these properties, since development work has continued irregularly on all of them, and their production is still increasing.

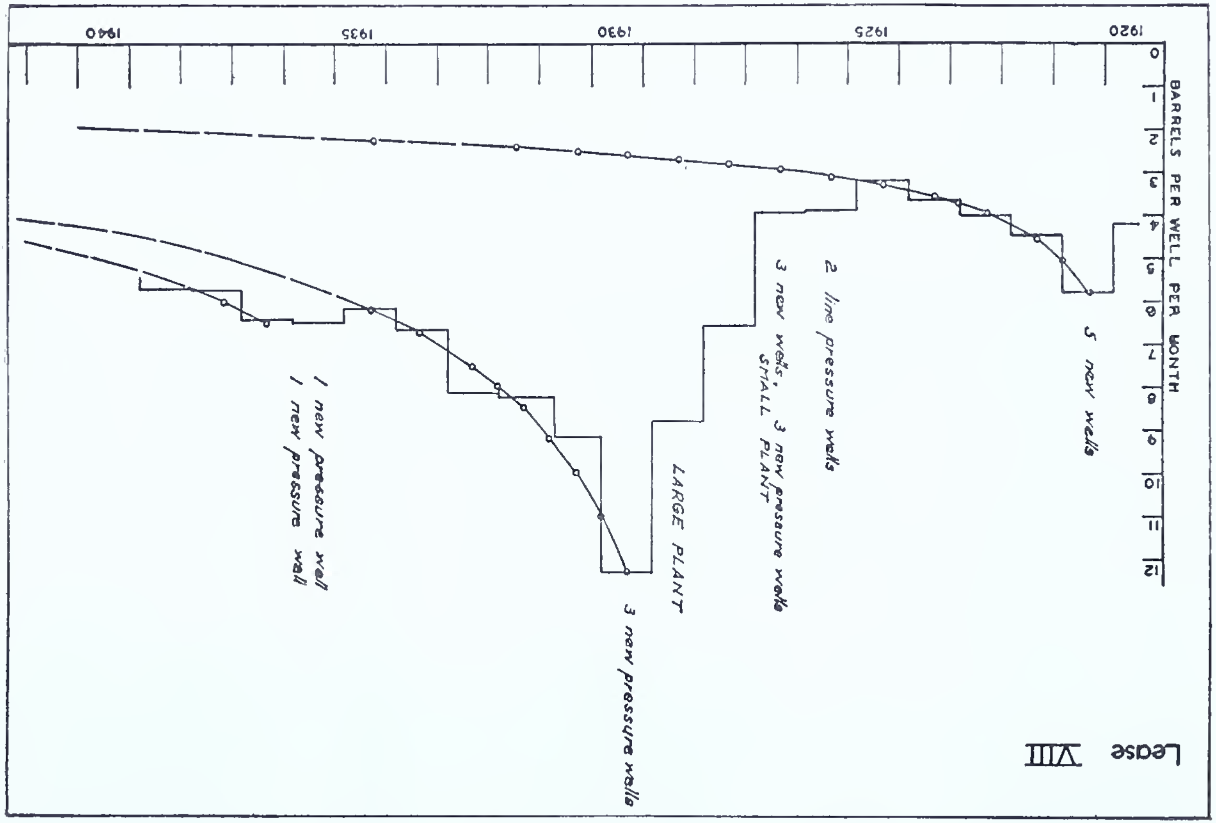

Figure 9. Production-decline curve, Lease VIII

An example of this type of development is Lease XIII, whose production curve is shown in Figure 10, and development map in Figure 11. The lease is underlain by Second and Third sands, which aggregate 30 to 60 feet in thickness. The Second sand is missing in parts of the lease, and is relatively impermeable elsewhere, so that most of the production has come from the Third sand. The pattern is a seven-spot slightly modified to fit lease conditions. Well-to-well spacing ranges from 250 to 300 feet. All air wells are cored, and have from two to six packers, so that air is injected at different pressures into as many as five different parts of the sands. The air input has been approximately 1,000 cubic feet per day per vertical foot of Third sand, but the Second sand has taken only small amounts of air at the pressures available.

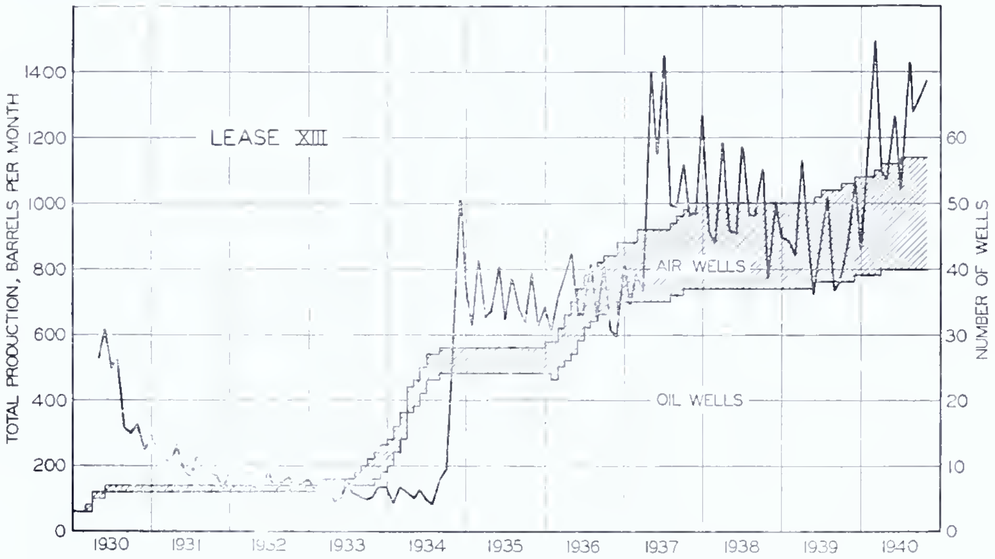

Figure 10. Production-decline curve, Lease XIII

The original development was started in 1930 and consisted of three old wells drilled in 1924, to which were added three new wells, forming a hexagon, and a new air well was drilled at its center. This group was operated experimentally until 1933. The decline in production may be plotted as a straight line on logarithmic paper, but cannot be used to estimate future recoveries from the lease, since each oil well is acted on by only one air well instead of three, as in a complete pattern. The air wells drilled to the south and north of this original group in 1936 and 1939 increased the production of the old wells about 700 percent.

During 1933 and 1934, 18 oil wells and 3 air wells were drilled increasing the developed area to 33 acres. Although 10 of these wells were drilled between April 1933 and June 1934, considerable increase in production did not occur until November 1934. Similarly a period of drilling during 1936 did not increase production until April 1937. The lag between drilling and increased production thus appears to be from 8 to 12 months.

The production declined from August 1937 to late 1939, and this decline would have been steeper but for the effect of wells drilled early in 1937. Wells drilled in late 1939 and early 1940 caused an increase which was still continuing in December 1940.

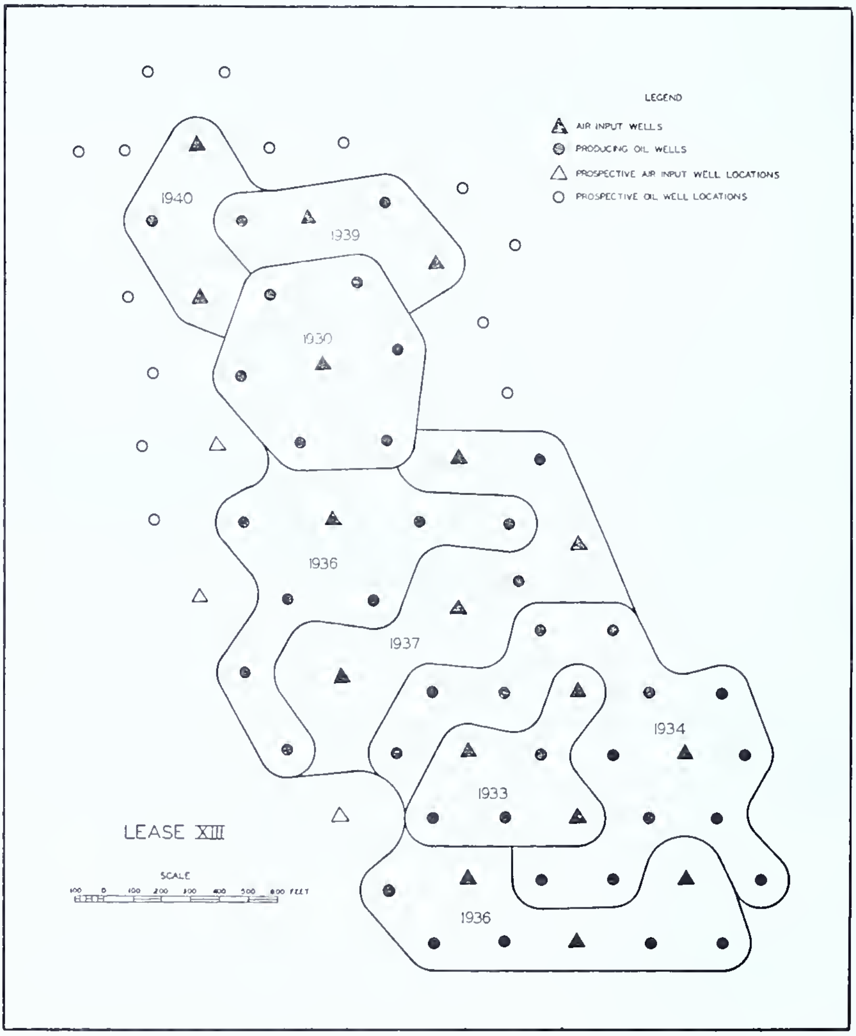
LEGEND
AIR INPUT WELLS
PRODUCING OIL WELLS
PROSPECTIVE AIR INPUT WELL LOCATIONS
PROSPECTIVE OIL WELL LOCATIONS
1940
1939
1930
1936
1937
1934
1933
1936
LEASE XIII
SCALE
100 0 100 200 300 400 500 600 FEET

Figure 11. Development map, Lease XIII

The total area drilled to October 1940 is 67 acres, and the cumulative oil production is 78,000 barrels. Had the entire area been developed during 1930 and 1931 the total production to date would have been far greater. Although there is no way of making an accurate estimate, it appears certain that the oil produced from the 67 acres will be not less than 135,000 barrels by 1950, a recovery of

2,000 barrels per acre. Accurate cost data on this lease are not available, but there is no doubt that this operation was profitable at the price of oil prevailing between 1930 and 1940.

Production and operating data for 12 leases for which it was possible to estimate the ultimate recovery are shown in Table 4, which is taken from a previously published paper (24). The method of estimating the ultimate recovery is more fully described in that article.

TABLE

Production and operating data from 12 leases under

	I	II	III	IV	V
1. Acres in lease affected by air.	76	60	35	40	260
2. Oil wells affected by air	26	20	17	16	76
3. Effective air wells (line wells count one-half)	7	8	3	3½	18
4. Acres affected by air divided by number of oil wells	2.9	3.0	2.2	2.5	3.4
5. Acres affected by air divided by number of effective air wells.	10.8	7.5	11.6	11.5	14.5
6. Name of sand	Third	Second	Third Stray	First and Second	First
7. Thickness of sand (feet)	20	35	20	30	20
8. Average porosity of sand (per cent)	12	13	12	...	22
9. Average oil saturation of sand (percent pore space occupied by oil)	24	...	20	...	23
10. Average oil content of sand (barrels per acre-foot)	230	210	225	300	330
11. Year air drive was initiated..	1936	1928	1929	1930	1915
12. Cumulative oil recovery with air drive from that year until December 31, 1939 (barrels).	11,500	12,571	6,001 [a]	27,978	146,164
13. Estimated future oil production, January 1, 1940, to economic limit (barrels)	6,800	11,800	2,750 [b]	42,000	52,000
14. Expected date of economic limit	1944	1954	1938	1965	1954
15. Number of oil wells contributing but unaffected by air ..	5	...	...	18	...
16. Estimated production of oil wells contributing but unaffected by air, from date of initiation of air drive to economic limit (barrels)	1,300	...	...	37,000	...
17. Estimated cumulative ultimate oil recovery with air, from date air drive was initiated to economic limit (barrels).	17,000	24,400	8,750	33,000	198,000

4.

air drive showing uninterrupted decline curves.

VI	VII	VIII	IX	X	XI$_2$g	XIg	XII	Average
45	133	61	61	16	50	24	37	
23	62	30	34	12	33	20	27	
6½	13	9½	8	3	12	7	8	
1.95	2.14	2.03	1.8	1.3	1.5	1.2	1.37	2.1
7.0	10.2	6.4	7.6	5.4	4.1	3.4	4.6	8.0
First and Second	Second and Third	Second	Third	Third Stray	Second and Third Stray	Second and Third Stray	First	
20 (Estimated)	35	24	37	40	20	20	22	
...	13	16	13	15	15	15	17	14.8
...	...	16	...	23	26	26	25	22.8
300 (Estimated)	275	325	275	300	300	300	360	287
1926	1926	1928	1930	1933	1926	1926	1935	
25,600	114,200	48,882	53,046	19,900	25,260[e]	7,400[c]	44,300	
7,000	92,000	26,900	58,000	25,300	50,000[f]	32,000[d]	36,000	
1943	1967	1951	1969	1955	1966	1955	1954	
8	...	15	...	6	...	...	...	
3,000	...	7,800	...	3,900	...	...	...	
30,000	206,200	68,000	111,000	41,100	75,260	39,400	80,300	

TABLE 4

Production and operating data from 12 leases under

18. Estimated cumulative ultimate oil recovery (bbls. per acre).	220	407	250	825	760
19. Estimated cumulative ultimate oil recovery (bbls. per acre-foot)	11	11.5	12.5	27.5	38
20. Average daily air input—date of initiation through 1939 (thousands of cubic feet) ..	...	65	...	120	...
21. Estimated air input per barrel recovery—date of initiation to December 31, 1939 (thousands of cubic feet per bbl.).	...	21.9	...	15.6	...
22. Time from initiation of air drive until production is less than 3 bbl. per month per well (economic limit) (years) ...	9	27	10	36	40
23. Time from initiation of air drive until ½ the ultimate recovery is obtained (years).	2½	11	3	15	11
24. Spacing factor; square root of the product, acres per air well times acres per oil well.	5.6	4.7	5.0	5.36	7.0

a Actual oil production, 1929-1933.
b Estimated future oil production, 1934-1938.
c Actual oil production, 1926-1929.
d Estimated future oil production, 1930-1955.

—Continued

air drive showing uninterrupted decline curves—Concluded

660	1,550	1,100	1,800	2,570	1,500	1,640	2,175	
33	44	46	49	64	75	82	100	43.1
...	250	275	220	...	...	...	110	
...	11.0	23.6	15.6	...	...	...	5.6	15.3
18	42	24	40	23	41	30	20	28
7	13	8½	11	8½	14	10	4	9½
3.70	4.66	3.61	3.70	2.65	2.48	2.02	2.51	4.1

e Actual oil production, 1926-1934.

f Estimated future oil production, 1935-1966.

g Two periods of decline following two periods of drilling on same lease.

FACTORS AFFECTING THE RECOVERY OF OIL BY AIR DRIVE

Bypassing of air. Since the permeability of the sands of the Venango group is extremely variable, as noted above, it is almost impossible to prevent most of the air from passing through the most permeable beds only. The air removes the fluids from these beds preferentially, thereby still further increasing their permeability to air. It is probable that channelling by the air takes place to a certain extent around every well. An exceedingly permeable sand will take large quantities of air at low pressure, and the injected air passes almost directly to a nearby output well. The air then has little effect in moving the oil in the other parts of the sand. It is obvious that even a small amount of bypassing may result in highly inefficient extraction of oil.

The most convenient way to determine the extent of bypassing of air is to take open-flow gauge readings of the air-gas output of the producing wells. An alternative method is to note the pressure build-up with time, as in gauging gas wells. These measurements are often supplemented by approximate analysis of the gas, either for B.t.u. content or by noting the color of its flame.

Methods of controlling bypassing of air. The use of multiple packers, as already mentioned, has become general practice in the Venango fields.

If an oil well shows serious bypassing of air owing to directional channelling, it is common practice to stop pumping for a time and allow a liquid head to build up in the well. The oil or water tends to enter the sand and plug the more permeable streaks, and bypassing of air often is stopped temporarily. Filling the well with fresh or salt water and allowing it to stand in the well until some of the liquid has penetrated the sands also has proved effective. Selective plugging by means of chemicals has been suggested but never attempted in the Venango fields.

It has been found that injecting air intermittently in 4-, 8-, or 12-hour cycles tends to inhibit bypassing. This probably is because large fluctuations of pressure occur in the open channels, and smaller fluctuations in the tighter parts of the sand where there is also more liquid. When the pressure drops in the open channels, the liquids, being at higher pressure, tend to migrate from the tight parts of the sand. During the next period of injection the liquids are forced along the open channels toward the producing well. The presence of the liquids in the open channels decreases their effective permeability, and the air is forced to act on the other parts of the sand. Where bypassing is severe very short injection cycles are beneficial.

Oil content of sands. It is obvious that the more oil in the sand when repressuring begins, the greater will be the recovery. It is certain also that a considerable quantity of oil in the sand cannot possibly be recovered economically by air drive. Laboratory work on *fully oil-saturated* cores indicates that 40 to 50 percent of the oil cannot be removed by air. When the cores are saturated first with water and then with oil, however, the oil remaining after prolonged air drives may be as low as 20 percent. On one property a pressure well from which air bypassed extensively through a permeable bed was abandoned for mechanical reasons, and a new well drilled forty feet away. It was found that the oil saturation in the permeable bed, through which large quantities of air must have passed, was 12.5 percent, equivalent to 124 barrels of oil per acre-foot. Experience indicates that probably very little oil can be recovered from a sand with an oil saturation as low as 15 percent (185 barrels per acre-foot at 16 percent porosity).

Spacing and pattern of wells. Results in both the field and laboratory indicate that the longer air passes through a sand the more oil will be recovered, and that the rate of production decreases with time and approaches zero asymptotically. The cumulative production of oil from a unit volume of sand is, therefore, some function of the quantity of air that has passed through it.

It is obvious that different volumes of air pass through unit volumes of sand in different parts of the sand body. For example, in a seven-spot pattern in a homogeneous sand, all the air injected must pass through the sand and come out at the producing wells. The volume of air passing through a unit cross section of the sand—which we may call flux density—is greatest at the walls of the holes, and decreases away from them. Greater volumes of air come out at the producing wells than go into the input wells, as the outlet pressures are much lower than the input pressures. If the pressure at the input wells is 300 pounds per square inch (gauge) and atmospheric at the producing well, the volume of air emitted will be 21 times the volume injected. There are twice as many producing wells as input wells in a seven-spot pattern, hence the flux densities in the neighborhood of the producing wells will approach ten times those in the neighborhood of the input wells.

Between the input and output wells in a seven-spot pattern, the air spreads out until, at three-fourths of the distance from input to output well, it covers a path 0.86 of the well-to-well distance in width. The greatest flow of air takes place along the straight line connecting the input and output wells, and decreases to zero at the points midway between the producing wells. Areas such as these through which little or no air passes will be very common in irregular patterns, and the oil may actually be concentrated in them. Pressure wells drilled recently between old oil wells on a lease which had been subject to air drive for more than twenty years showed abnormally high saturations which were unquestionably due to secondary enrichment.

Problems involving the flow of gases through porous media are more complicated than the flow of incompressible fluids. For liquids, the pressure distribution can be worked out by electrolytic conduction models, no matter how irregular the pattern. Theoretical work showing the distribution of the flux densities for gases likewise would be instructive and permit determining the relative efficiencies of various patterns. Efficiency is used here in a sense different from that used in connection with water flooding. The pattern that gives the most uniform distribution of flux density between wells is considered the most efficient.

Although the importance of efficient patterns needs emphasis, irregularities in the sand body will spoil the efficiency of any regular pattern. Some of the sand bodies in the Venango fields consist of a series of long, parallel bars or thick streaks, 1,000 to 2,000 feet wide. Between the bars the sand is much thinner and apparently less porous and permeable than in the thick streaks. Whenever possible, the location of such impermeable streaks and spots should be given full consideration in the layout of well patterns.

Other factors. Air has an oxidizing effect on crude oil, forming compounds that make it more difficult to recover. Some of these compounds are insoluble and tend to clog the pores of the sand; others cause stable oil-water emulsions. The long-continued passage of air through oil sands removes many of the lighter hydrocarbons and increases the specific gravity and viscosity of the oil. The use of air introduces other mechanical difficulties, such as corrosion of equipment and the formation of explosive mixtures.

Better oil recoveries than are possible with air as the injection medium might be obtained by driving with a gas that is soluble in the oil. Gas coming out of solution forms bubbles that tend to clog the pores of the sand, which otherwise would transmit gas only. On the other hand, some of the driving effects would be lost as the result of the gas going into solution.

Although it might be difficult to show that the advantages of natural gas as a driving medium justify its purchase at a price in excess of 40 cents per thousand cubic feet, the gas still remaining in the sand should be carefully conserved by using outside sources of power and by collecting vapors produced with the oil from flow lines and receiving tanks.

Other factors that have an important effect on oil recovery by air drive are the viscosity of the oil, the percent of pore space of the sand occupied by water, and the permeability of the sand. It is believed, however, that the effect of these factors on the recovery of oil from the leases studied was less than the effect of the bypassing of air, oil content, and well spacing. These factors are more susceptible to laboratory investigation than the major ones. Insufficient data were available to attempt to evaluate their importance.

Fundamentally, it is the energy of the expanding and moving air that moves oil to the wells, and energy input can be calculated from the volume and pressure of input air. However, bypassing causes such a variable and unknown waste of energy, and inefficiencies of pattern cause such a variable distribution, that it is difficult to estimate the quantity of energy required to recover a barrel of oil.

EFFECT OF WELL SPACING

The cumulative recoveries from the leases studied were plotted against a well spacing factor, consisting of the geometric mean of the input and output wells (square root of the product, acres per oil well times acres per air well) (Fig. 12). The points scatter rather badly, as would be expected from the irregularities of the pattern, the effect of bypassing, and the different oil content and characteristics of the sand, but there appears to be a definite relation. It seems reasonable to assume that as the well spacing is decreased to very small values the quantity of oil recovered will tend to approach as a limit the total recoverable oil in the sand, or about 140 barrels per acre-foot, since the average total oil content of the leases shown is 290 barrels per acre-foot, of which 290 minus 150, or 140, are recoverable. At the other end of the curve, as the well spacing is increased so that there are many acres per well, the recovery per acre will diminish and gradually approach zero. A curve with the formula $y=ae^{-bx^p}$ has these properties, and is drawn in figure 9 as a solid line. (y = cumulative ultimate recovery in barrels per acre-foot, a = total recoverable oil, x = well spacing in acres per well, e = base of Napierian logarithms, b and p = constants depending on local conditions.)

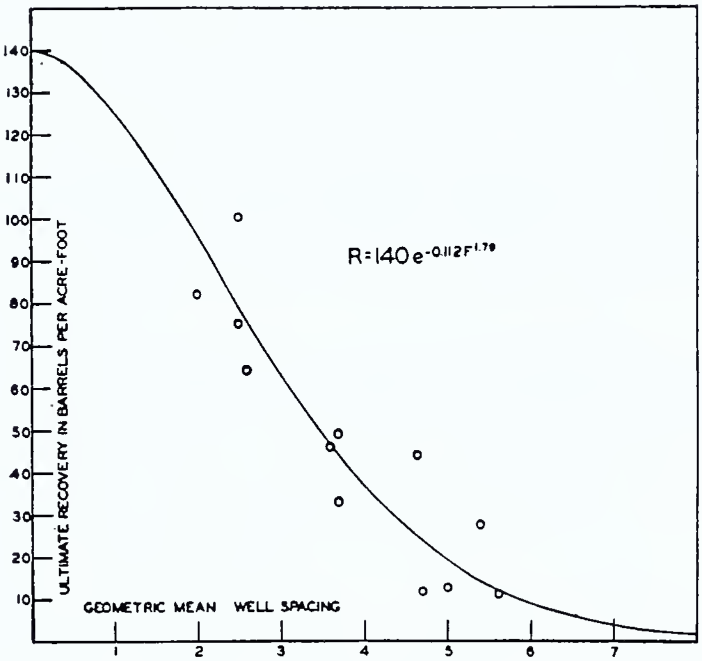

Figure 12. Cumulative ultimate oil recovery of 12 leases plotted against well spacing

The leases used in plotting this curve have, however, different total oil contents, and the leases with the higher ultimate recoveries have the higher oil content, so that it would be more correct to relate the spacing to the fraction of total recoverable oil which will be recovered, instead of to the actual oil recovered. This is done in Figure 13, and the type of equation is the same. Values were assigned to the constants by the method of least squares, so that the curve fits as closely as possible the actual spacings and recoveries of the twelve leases on which data are available. The formula becomes

$$R=e^{-0.29F^{1.09}}$$

where R = fraction of total recoverable oil recovered at spacing F.

Additional recovery data are necessary before this equation can prove its general applicability. However, it will serve as a rough guide to determine the most economic spacing to use in laying out an air-drive program in the Venango district.

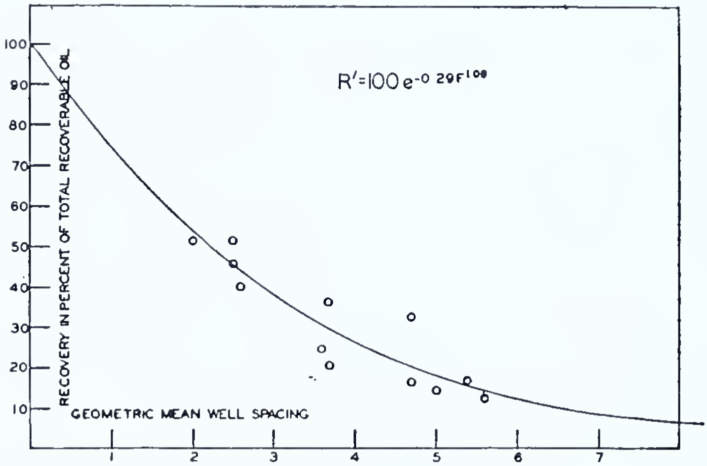

Figure 13. Oil recovery of 12 leases expressed as percent of total recoverable oil, plotted against well spacing

OPTIMUM SPACING

An operator intending to install air or gas drive on an old property is confronted with the problem of how many new wells should be drilled to make the greatest profit. As shown in the preceding section, the more wells he drills the more oil he will recover, but the greater the number of new wells the greater will be the development cost, and drilling too many wells will obviously result in decreasing his net profit. The determination of the most profitable or *optimum* spacing is exceedingly complex and difficult, and has probably never been accurately established for any oil producing district. However, if the equation on the preceding page is valid, one method of calculating the optimum spacing may be suggested.

Various considerations affect the profit or net return on an oil property. The principal ones are: price per barrel received for the oil, lifting cost per barrel, and development cost per acre. If these values are taken into account, the net return per barrel may be expressed as follows:

The money received per acre from the sale of oil will be the total quantity of oil recovered multiplied by the price per barrel. If we assume that the oil in excess of 150 barrels per acre-foot is recoverable, that the sand has a thickness of T feet, and that the recovery factor for the spacing we shall use is R, then the total quantity recovered will be TR(C-150) barrels. This multiplied by the price per barrel will be the gross income. The operating cost will be the same number of barrels multiplied by the operating cost per barrel.

The development cost per acre will be the development cost per well divided by the number of acres per well. This may be expressed by an equation:

$$\text{Profit} = P = KTR(C\text{-}150) - LTR(C\text{-}150) - \frac{JN}{A}$$

P = net return per acre
K = price of oil per barrel
T = thickness of sand
R = recovery factor:—fraction of total recoverable oil recovered at geometric mean spacing factor F
C = oil content of sand in barrels per acre-foot
J = development cost per well
N = number of new wells drilled
A = acres in lease

The equation may be simplified to read

$$P = TR(C\text{-}150)(K\text{-}L) - \frac{JN}{A}$$

The value of R is determined by the equation

$$R = e^{-.29F}$$

where F is the geometric mean spacing factor, square root of the product, acres per oil well times acres per air well.

Each operator may assign values to the above symbols to fit conditions on his lease, and calculate the number of wells which will give the greatest profit.

Calculations of examples typical of the Venango district were given by the authors at the Eastern District meeting of the American Petroleum Institute, April 17, 1941, but could not be included in this report.

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TABLE 5

MAP NUMBER	NAME	OWNER	ELEV.	FIRST SAND	WHITE (Amber)	RED VALLEY (Lytle)	2nd.SAND (Salt)	3rd.STRAY (Gray) (black oil)	3rd.SAND (4th.SAND) (Green oil)	OTHER SANDS	TOTAL DEPTH
1	Poet well		1548	345-399					shells		
2	Matteson #1	George Matteson	1589	382-453					657-667		701
3	Early well	(See deep well table)									
4	Grey well	" " " "									
5	Post well	" " " "									
6	Paul well	(See deep well table)									
7	Drake well		1163	Oil encountered in stray sand at 69½ ft; subsequently deepened to Third Sand.							
10	Hasson #3	Rulin Kerr	1730	455-510					725-760		780
11	Swede #11	Rigby	1565	314-360					574-605		614
12	Bailey #13	Johnson Bros.	1587						613-648		687
13	Fuller #2	Johnson Bros.	1556						584-625		645
14	Morris well	(See deep well table)									
15	Dunlap #16	Johnson Bros.	1505						550-593		618
16	Gilson #7	" "	1502						567-603		607
17	Harrison #11	Johnson Oil Co.	1507						573-608		638
18	Harrison #5	Johnson Oil Co.	1568						616-650		661
19	" #2	W.G. Roeder	1630						685-721		726
20	Shaw #1	Edwards	1599						670-695		
21	Kerr #11	South Penn Oil Co.	1545						625-659		685
22	Hummer #1	J.C. Hummer	1530	335-392				576-585	606-637		
23	Hummer #5	J.C. Hummer	1568	376-429				620-630	650-677		
24	W.C.Kerr #8	Logan	1476						586-611		630
25	" " #2	"	1573						680-710		731
26	Newton gas well	(Bayliss, Bloss & Wege	1624	475-515				676-717	740-780		
27	Brown #5	Summerton & Sutton	1615						727-788		813
28	Cochrane #1	Summerton & Sutton	1618					677-707	713-787		811
29	Drake #5	" "	1439	280-340				520-544	559-591		670
30	Marsh #7	" "	1650	470-521				716-723	752-807		
31	Sutton #20	Bayliss, Bloss & Wege	1623	472-486				694-704	735-785		825
32	Foster #1	" " "	1596	447-				688-700	726-750		760
33	Hummer # CW3	Petroleum Reclamation Co.	1548						684-722		
34	J.F. Hummer #9	Vance Weld	1572						705-729		753
35	Wieland #1	" "	1608						735-752		782

TABLE 5 (Continued)

36	Gilson #7	Vence Weld,	1567						700-740	775
37	Voesburg #4	Petroleum Reclamation Co.	1555						691-736	
38	C.Kerr #13	Church Run Oil Co.	1556						692-738	700
39	Muir		1690	451-480						497
40	Holmes #2	Roaa Holmes	1661	429-454						465
41	Fertig #9-A	Aetna Crude Oil Co.	1529	312-340						
42	Stull #1	C.E. Ditmen	1721	519-579						595
43	Bughman #9	Petroleum Reclamation Co.	1681	495-523						542
44	Brown #11-E	" " "	1562	382-417						
45	" #29-B	" " "	1530	360-393						419
46	Ongley #1	O.T.Onglay	1638	465-530				704-740	744-	762
47	Millar #2	H.E. Onglay	1625					688-722	-739	753
48	Byles #34	National Pet.Co.	1512	330-380				561-597	606-618	639
49	Onglay #6	" " "	1514	350-397				583-	617-629	671
50	Foeter #11	See deep well table								
51	C.W.X.	See deep well table								
52	C.C. Gilson #9	John Andereon (dry)	1693	464-493					703-716	743
53	White well	Carll I-4 p.52	1610	385-415						415
54	Ackarman well	" " "	1673	434-477						481
55	Morris well	" " (dry)	1530	358-398					610-shell	
56	R.T. Gilaon #29		1652	440-475						512
57	Marah #5	See deep well table								
58	Knupp #2	" " " "								
59	Hummer well	" " " "								
60	Moll #22-M	Petroleum Reclamation Co.	1490	313-352						
61	Ott #14-A	Sande O'Pann	1438	250-312				512-541		
62	Matkovich	" "	1634	448-479				633-722		723
63	Churn #10	J.P.Eaton Corp.	1618	446-484						492
64	Bylas #21	National Pat Co.	1478	313-365				535-568	576-593	615
65	Smith #5	Baylies,Bloss & Wege	1580	428-463				666-699	690-707	707
66	Tarbell #74	Bayliss,Bloss & Wege	1600	450-492				680-710		726
67	" #35	" " "	1339	208-258				441-471		475
68	Thomas #50	Goel Oil Co.	1323	214-236				436-460	467-477	480
69	" #43	" " "	1581	461-490				689-708		744
70	Landas #30	Penn Fields	1577	470-499				700-715	730-736	740

MAP NUMBER	NAME	OWNER	ELEV.	FIRST SAND	WHITE (Amber)	RED VALLEY (Lytle)	2nd. SAND (Salt)	3rd. STRAY (Grey) (Black oil)	3rd. SAND (4th. Sand) (Green Oil	OTHER SANDS	TOTAL DEPTH
71	Mead #36	National Pet. Co.	1662	540-565				769-787			
72	Harris #1-A	W.E. Fertig	1593	496-520					718-742		742
73	Wales #22	Netional Pet. Co.	1685					794-819			859
74	" #5	Fred Weles	1652	538-575				772-793	806-820		825
75	Knepp #5	Nationel Pet. Co.	1636					740-766			
76	Knepp #7	Nationel Pet. Co.	1668					786-810	824-833		852
77	DeMills #15	" " "	1626					750-771			782
78	Sturgie #21	Minnick Bros.& Kenemath	1530	390-457			548-	638-661	676-688		
79	Thompson #11	Denman & Mellory	1516	438-463			534-554	640-664			680
80	Wekemen #3-A	Nationel Pet. Co.	1641	505-562				747-770			795
81	VanWyck #6	National Pat. Co.	1569	423-476				663-685	701-711		711
82	Stanton "B"	" " "	1603	463-526				705-734			737
83	Campbell #5-E	" " "	1586	440-476				669-703			730
84	" #3-D	" " "	1622	474-514				705-742			769
85	Benedict #32	R.M. Averill	1592	460-489				686-715	723-729		755
86	Campbell #19	R.M. Averill	1674	531-560			672-675	763-784	794-814		823
87	Bleakley #1-A	Scofield	1687	570-593				793-809	826-843		872
88	Merritt #25	R.M. Averill	1686					782-818			827
89	Zene "C"	Nationel Pet. Co.	1608	457-481				674-713			715
90	Bleakley #22	R.M. Averill	1587					675-706			736
91	Reeves "B"	National Pet. Co.	1555	393-428				627-670			673
92	Crippen # 1-A	W.E. Fertig	1631	502-524				720-761			772
93	Bovee # "B"	" "	1612	466-471				693-736			739
94	Huidekoper #7	National Pet. Co.	1420					492-539			557
95	Stenford#17	L.C. & R.B. McKinney	1315					378-420	425-449		501
96	Wood #19	L.C. & R.B. McKinney	1515					595-643			673
97	" #35	" " "	1620	450-500				698-744			753
98	#42	" " "	1609	450-480				674-714	714-736	745-751	753
99	Brown #2	J.P.Eaton Corp.	1390					449-496			522
100	Burleigh #6	McKinney	1628					688-723	725-749		763
101	Loomis #2	J.P.Eaton Corp.	1414					451-491			526
102	Grendin #8	J.E. Fleming	1481					510-578			

103	Dunderdale #29	J.E. Fleming	1474					510-548			
104	Thompson #1	"	1393					430-472			
105	Thomas #6	"	1579	362-				592-635			659
106	Radke #4	V. Lofgren	1718	470-505				692-722	740-755		808
107	Snyder #2	"	1618	332-361				551-585	596-612		641
108	Lofgren #2-A	V. Lofgren (dry)	1569	470-478				660-684	696-703		719
109	" #3-A	"	1581					585-606	622-639		673
110	Brown #1	J.E. Fleming	1682	499-506				695-737			
111	Reno #7	"	1527					553-613			
112	Adams #22	"	1583					619-669			
113	Lamarie #15	J.E. Fleming	1652					687-740			
114	Lanning #29	J.P. Eaton Corp.	1693					747-797			816
115	" #30	" "	1715					761-819			843
116	Polly Putnam #14	" "	1657					700-755			785
117	Emerson #1	L.C.& R.B. McKinney	1663					710-780			806
118	Jones #27	L.C.& R.B. McKinney	1719	561-567				773-840			847
119	Gibbs #24	Luke,Moran & Dunbar	1707					779-825			857
120	Grove #13	J.P.Eaton Corp.	1645					718-763			
121	Peterson #16	" "	1693					770-812			812
122	" #36	" "	1662					739-765			788
123	Bright #21	J.P.Eaton Corp.	1523	367-387				610-640			
124	Crocker #48	" "	1725	568-598							
125	Jones & Gregg #28	Gregg	1540	415-435			557-567	643-667			687
126	Sowles #1	Burt Sowles	1600	481-505				711-729			755
127	#15	"	1633	516-540							
128	American #5	Commercial Lbr.Co.	1473						443-449		
129	Leet #4	F.Leet	1494						486-495		
130	Reynolds #2	W.D. Redmond	1565	281-316					554-559		
131	Churchill #1	J.M.York	1517	222-257					497-510		
132	Phila.#83	J.P.Eaton Corp.	(See deep well table)								
133	Lofgren #2	V. Lofgren	(See deep well table)								
134	Atlas well	J.F.C.	1520	337-357					530-578		932
135	Gregory #5		(See deep.well table)								
140	Emery Ames #10	National Pet. Co.	1652	520-580				770-786			
141	Harris #6-A	W.E. Fertig	1594	486-533				721-742			742

MAP NUMBER	NAME	OWNER	ELEV.	FIRST SAND	WHITE (Ambar)	RED VALLEY (Lytle)	2nd.SAND (Salt)	3rd.STRAY (Gray) (Black Oil)	3rd.SAND (4th Sand) (Graen Oil)	OTHER SANDS	TOTAL DEPTH
142	Hopkins-Banedict #27	National Pet. Co.	1631	535-581				769-787			801
143	" " #49	" " "	1626	527-553				765-775	798-806		808
144	" " #19	" " "	1613	528-568				761-776			791
145	Wales #10	Fred Wales	1631					757-774	788-797		802
146	Jack #20	" "	1625					759-777			805
147	Campbell #23	Fred Walas	1637	550-560				766-789	804-812		813
148	Huntar # H-A-4	Wilson Bros.	1597	510-542				737-751			754
149	Henderson #20	" "	1629					762-776			802
150	" #1-A-B	" "	1406	342-370				555-580	590-595		598
151	Dalo #10	National Pet. Co.	1595					731-753			770
152	Henderson #5	National Pat. Co.	1569					714-759			759
153	Penn-York #9	Penn-York	1393				433-446	541-573			
154	Carpenter #7	Ralph Vail	1346	225-285			380-398	485-525			533
155	" #12	Haakall Bros.	1646	544-572				782-827			862
156	Potter #1	Peterson-Johnson	1445	330-385			470-480	573-614			621
157	Dodd & Oakes #4	Paterson-Johnson	1454					584-624			655
158	Clapp #18	" "	1492	402-412		467-474	523-531	620-664			712
159	Benson #19	National Pet. Co.	1563	491-523				726-743			757
160	T.L. Cheney #5	" " "	1608	557-587			692-712	796-818			875
161	J.Cheney #17	" " "	1398					590-619			632
162	Sheppard #17	National Pet.Co.	1464					648-667			681
163	Wright #32	Clingar O & G. Co.	1344	275-		298-314	407-426	516-542	550-570		579
164	Watson #18	" " "	1481	425-434			546-570	651-685	689-695		716
165	Colorado #43	" " "	1315	219-281			362-380	468-507			533
166	Stevens #32	W.J. Stevans	1354	-310			-419	507-547			568
167	Colorado #8	Clinger O & G. Co.	1505					660-693			704
168	Shank #38	" " "	1404	329-344		410-418	458-468	566-597			664
169	Mt. Hope	Logan	1594	536-547				782-796			851
170	Stroup #3	W.E. Ongley	1243	194-214			333-342	459-471			571
171	Conover #6	Logan	1337				411-436	522-527	551-562		576
172	Benedict #9	Fred Wales	1363	315-350			440-460	550-560	577-589		608
173	Carson #14	So. Penn Oil Co.	1608			633-650					676
174	Brynar #10	" " "	1575			589-603	643-662	745-760	778-787		
176	Ruland #1	L. Winitzky Estate	1605			602-622					640

177	Baughman #11	National Pet. Co.	1341	290-322			428-448		564-578		599
178	Sheppard #3	G.Grubb	1447						670-685		
179	Coulter #11	Plumer, Coulter	1508				642-652		771-785		
180	Pittsburg #6	National Pet. Co.	1430				520-549		654-669		683
181	Dunham #25	Haskell	1628			654-670					698
182	Dunham #13	Haskell	1654			667-689					719
183	Mixer #10	Keeley	1598			606-630	-685	759-771			909
184	Pratt #8	"	1657			660-681					707
185	Crossman #22	Leo Benedict	1620			621-638	-695	776-784			889
186	Fobes #37	" "	1584	526-553		604-624					625
187	Kingeley #4	W.E. Fertig	1588			601-621					646
188	Shelmadine #9	" "	1577			591-612					643
189	Collins #1	Mrs. Wilson	1648			667-686					715
190	Wilson #22	Bailey Bros.	1550			556-576					
191	Minnesota #24	Mrs. Wilson	1622			631-652			876-		
192	Collins #1	J.M.Karl	1554			575-594					624
193	Carson #2	"	1615	574-589		644-654					693
194	Fleming #5	National Pet. Co.	1607			610-622	655-675		793-807		820
195	Mason #5	J.M.Karl	1621			654-665					694
196	Ruland #2	"	1605	553-563		622-642					671
197	Minnesota #12	Mrs. S.Q. Wilson	1529			532-552					577
198	Cattaraugus	" " "	1528	465-475		540-560					587
199	Bailey #16	Bailey Bros.	1626	-562		620-640					655
200	" #7	" "	1637	537-575		633-649	682-709	791-795	828-838		843
201	" #37	" "	1536			524-547	607-		736-		736
202	Wilson Bros.#19	Mrs. S.Q. Wilson	1540			525-548					571
203	" " #37	" " "	1537			517-543					568
204	" " #47	" " "	1537			525-543		677-			743
205	Crandall #1	D.N.Burrows	1611			620-541			819-		844
206	Carson #18	Bob Carson	1568	450-		538-562		692-701	735-751		755
207	Spangler #12	W.R. Mitchell	1509			489-520					545
208	Cozy Oil Co. #17	Kerr & Small	1510	405-440				635-650	670-710		771
209	" " " #45	" "	1433	312-347				540-560	578-630		720
210	Cummins #16	Cummins,Roesa & Parker	(1530					653-670	680-727		732
211	Pure Penn Pet Co.#6	Nutting,Key & Thatcher	(1543					674-728			771
212	Cummins #1	Cummins,Roess & Parker	(1435					560-573	596-640		654
213	Mary Sloan #4	W.J. Stevens	1531					656-674	694-725		

Map Number	NAME	OWNER	Elev.	First Sand	White (Amber)	Red Valley (Lytle)	2nd. Sand (Salt)	3rd. Stray (Grey) (Bleck Oil)	3rd. Sand (4th Sand) (Green Oil)	OTHER SANDS	TOTAL DEPTH
214	F. McGuire #10	W.J.Stevens	1527	430-469				669-684	704-745		760
215	A.N. Werner#"22	Warner-Celdwell Co.	1556	449-489				677-691	717-765		800
216	A.N.Werner #16	" " "	1516	420-460				650-662	685-739		
217	L.L.Sterling #9	" " "	1419						592-644		696
218	Hood #23	Meed & Hood	1358					500-510	533-598		648
219	Bernsdall #19	Meed & Hood	1477	409-427				636-648	674-723		765
220	Weed #113	Oil Creek Refining Co.	1517	443-472				671-690	707-765		780
221	Weed #133	" " " "	1513	443-470				675-709	713-775		785
222	Roggencamp #15	F.A.Roggencamp	1505	430-490				566-685	705-750		780
223	Dardee #8	Campbell	1545	480-545				708-737	747-791		799
224	Dale-McGee #15	Chambers Oil Co.	1581	500-561				738-760	771-816		863
225	Nieman #8	Campbell	1530	482-528				705-728	748-781		798
226	Rice #4	So.Penn Oil Co.	1602						802-846		866
227	Green #10	" " "	1492					662-693	702-747		772
228	Herrington #5	" " "	1220						458-496		507
229	Allison #30	Goel Oil Co.	1337	244-280							307
230	Keiley #5	" " "	1558	435-478				680-692			718
231	Reinherdt #2	R.Reinherdt	1565	481-504							536
232	Weugenknecht #7	J.J.Hervey	1527	490-500							525
233	Holtz #21	J.W.& R.L. Holtz	1598	593-608			705-716				749
234	Holtz #16	J.W.& R.L. Holtz	1591	565-			698-710				728
235	Grendin #44	J.J.Hervey	1577	526-572			676-686				707
236	Grendin #16	" "	1615	572-612			715-727				765
237	Siggins #24	Lytle Estete	1558	544-586		658-660	683-695	760-780			787
238	Bryen #37	Bryan Oil Co.	1640	603-643			744-762				786
239	Beebe #30	W.E. Fertig	1648	636-658			756-776				802
240	Beebe #34	" "	1687	690-697			801-818		937-950		1000
241	Skinner #15	C.L.Skinner	1674	650-675			777-800		914-929		970
242	Foss #6	" "	1625	595-625			728-744		874-884		923
243	Oiler #10	Henderson Bros.	1610	603-627			741-751				790
244	Henderson #4	" " "	1668	683-696			796-812		945-949		1215

245	Henderson #6	Henderson Bros.	1654	678-696			785-795				1000
246	Siggins #34	Lytle Estate	1673				785-803		926-942		
247	Spangler #20	A.L.Spangler	1648	647-659			760-775				823
248	Spangler #16	C.L.Spangler	1615	619-629			730-750		868-884		909
249	Rooker #3	V.Redfield	1684				781-810		931-951		1011
250	Propheter #3	Ed. Propheter	1630			687-693			868-893		
251	Stewart #4A	W.H. & J.A. Roeder	1501	496-523							
252	Parshall #4	V.Moore	1622	614-623			756-778		902-907		890
253	Spangler #3	C.L. Spangler	1585				694-717		839-855		
254	Grant #38	So. Penn Oil Co.	1572	355-397			683-712	794-809	828-854		
255	Grant #39	So. Penn Oil Co.	1552	535-560			672-694	773-785	813-833		
256	Nat. Transit #9	J.R. Preston	1191						430-456		483
257	Kerr # "E"	W.E. Fertig	1180	160-166				370-377	399-450	58-60	450
258	Kingsland #11	J.R.Preston	1171						413-445		531
259	Roden #9	" "	1155						407-442		492
260	Sloan #15	Surety Oil Co.	1542						780-830		880
261	Purtle #25	" " "	1605						862-906		1008
262	Staub #1	" " "	1462	459-493					727-770		799
263	Hyde #15	"D" Oil Co.	1571						837-877		896
264	Gilson #1	Surety Oil Co.	1594						877-912		951
267	Harmonial well	(from J.F.C.)	1620	576-616				707-747	812-830		835
268	Dodd & Oakes	(See deep well table)									
269	Shank # 30	" " " "									
270	Leyendecker	" " " "									
271	Wilson well	" " " "									
272	Burrows well	(See deep well table)									
274	Watson deep well	(See deep well table)									
275	Selkirk well	" " " "									
276	Boughton well	" " " "									
278	Shamburg #2	" " " "									
279	Fertig well	" " " "	1133						457-492		514
282	United States well	(famous Pithole discovery well, no record available)									
283	Homestead well	(no record)									
284	Hoosier well	(from J.F.C.)	1363	357-381		457-487	590-610				643
285	Zuver # 37	(See deep well table)									

Map Number	NAME	OWNER	Elev.	First Sand	White (Amber)	Red Valley (Lytle)	2nd Sand (Salt)	3rd.Stray (Gray) (Black Oil)	3rd.Sand (4th.Sand) (Green Oil)	Other Sands	TOTAL DEPTH
286	Hunter #4	(See deep well table)									
287	Vanderlin well	" " " "									
288	Linden well	J.F.C. 1-4 p.59	1589	620-660		703-725	768-785	877-878	914-916		924
289	Foster #8	O'Bail Oil Co.	1537	550-585				796-805			839
290	Fulmer #11	" " "	1563	580-615				819-825			869
291	Breed # 15	O'Bail Oil Co.	1503	531-556				760-767			807
292	Purtle #2	" " " "	1597	585-620				820-826	855-		870
293	Bennett #2	" " " "	1511	525-555				763-773			814
294	Steub #3	"D" Oil Co.	1503	514-552				761-768	794-809		814
295	Wagner #5	Wagner	1540	539-575							605
296	Gibson #12	Bayliss & Bloes	1517	512-546					782-824		857
297	Gibson #5	" "	1458						727-777		800
298	Wagner #8	Wagner	1539	533-565				757-	800-851		
299	Ingraham #13	Surety Oil Co.	1518	514-					777-826		906
300	Bunce #5	" " "	1584						840-883		
301	Curry #11	Surety Oil Co.	1610						880-920		970
302	Lamb #40	"D" Oil Co.	1582						847-906		964
303	" #59	" "	1624						899-943		996
310	Benninghoff #37	Success Oil Co.	1197	248-					538-577		608
311	Straub #19	W.E.Fertig	1097						441-467		482
313	Davis #15	National Pet. Co.	1356	425-465			565-590	669-674	700-728		779
314	Carter #3	" " "	1263	320-370			458-486	557-566	590-620		667
315	" #9	" " "	1459	520-565			654-682		800-827		885
316	Voorus #1	A.E. Lawson	1564	625-665			765-796	875-885	911-930		980
317	Russell #3-V	Carlberg	1525	590-630			730-757	835-848	875-882		944
318	Pettigrew #11	A.E. Lawson	1524	609-661			749-774	854-864	895-905		905
319	Amber #14	Behringer	1556	644-706			791-819	910-			980
320	" #20	" "	1518	620-640			755-782	865-875			912
321	Russell #11	Kern	1463	560-601			711-730	811-820	847-853		862
322	Haupt #16	L.Emele	1450	554-601			704-730				903

323	Breden #24	Davidson Est.	1377	477-533			621-644	728-733			
324	" #6	" "	1373	-540		572-594					
325	J.V.Smith #9	A.E. Lawson	1487	610-646			743-772	860-869	892-923		923
326	Voorue #14	J.Berry	1595	655-695			790-822	900-910	938-		954
327	Wateon #26	Wateon	1595	645-678			782-799	876-887	928-953		1006
328	Pittsburg #14	C.W.Seeward	1560	616-648			749-773	851-861	893-917		996
329	" " #27	" "	1482	492-500	544-558		662-693	764-775	806-845		
330	Weekley # B-2	Shamburg Expl.Co.	1635				798-825		948-976		1030
331	Locke#34	R.Locke	1624	653-685			790-813		934-972		
332	" #27	"	1567	605-645			740-763		900-910		954
333	Miller #9	J.E. Fleming	1383	412-462					682-745		
334	Atkinson #104	A. Thetcher	1526				680-700		829-838		
335	" #56	"	1593				735-755		876-926		976
336	Cecil #7		1513	536-564			660-685		797-814		
337	Benninghoff #15		1405				555-575		692-705		
338	Andrews "A"	Shamburg Expl.Co.	1536				678-698		815-863		
339	Jordan # 1-C	" " "	1510	518-558			660-688		795-844		896
340	Roth #41		1502	605-645			757-782		891-931		
341	Southeest #22	Wm. Fleming	1636						918-942		984
342	Jeckeon #17	R.M.Davidson Eet.	1653	646-666			773-796		914-946		995
343	Farrel #31	Foggan	1669	674-684			795-821	897-907	934-970		1012
344	Chandler #22	M.F.Folwell	1593	572-602			707-727		850-880		920
345	Holbrook #32	W.E. Fertig	1560				-690	776-779	813-833		871
346	Cole #1-Q	T.C. Kingsley	1594	550-600			700-720	801-811	842-864		
347	" #15-D	" "	1611				708-730	814-824			
348	Wilbur & Beason	(Red Valley Oil Co.)	1576	564-582		658-662	702-722	804-815	843-864		866
349	Fullerton #20	So. Penn Oil Co.	1554	544-579			673-706	775-780	817-847		
350	Chicago #8	G.R. McCrey	1642	680-685			787-809	889-899	927-963		
351	Boyle #51	J.A. Boyle	1557	590-610		655-673	705-727	805-819	847-867		921
352	Clark #63	R.Foggen	1628	683-			792-815	899-907	934-966		1037
353	Clark "A-2"	Netionel Pet. Co.	1574	590-625			717-745	822-830	862-874		890
354	Dawson #19	W.J.Stevens	1468	490-528	576-582		632-650	730-745	772-786		834
355	Kingsbury #1-A	P.S. Gardner	1630	677-696		751-770		908-916			916
356	Smith # 15	E.C. Breene	1402	465-504			602-632	706-722	750-760		802
357	Griffin #12	" "	1486	560-		652-662	706-721	802-813	841-846		870

MAP NUMBER	NAME	OWNER	ELEV.	FIRST SAND	WHITE (Amber)	RED VALLEY (Lytle)	2nd.SAND (Selt)	3rd.STRAY (Grey) (Black Oil)	3rd.SAND (4th Sand) (Green Oil)	OTHER SANDS	TOTAL DEPTH
358	Keech & Allison #10	(W.E. Cubbon	1502			666-686	720-742	826-835			861
359	O'Leary #2-A	Gordon	1562			741-750	792-810				
360	Russell #16	E.C. Breene	1519			695-703					
361	" #11	" "	1596			773-783	936-				
362	Cubbon Bros.#22	W.E. Cubbon	1555			729-749	790-809				829
363	Oberly #3	W.E. Cubbon	1421			599-618	661-678				696
364	Shamburg #1-P	Ashworth & McCray	1588	659-721		774-782	825-845				850
365	Sleter #17	R.M. Davidson Estete	1640	602-622		691-705	740-768	849-857	886-906		1000
366	Holtz #12	" " "	1660	581-623		688-708	744-764	846-858	886-901		1008
367	Welters #11	" " "	1588	524-553		618-639	672-696	774-786	814-829		986
368	Lamb #10	R.M. Davidson Estate	1584			600-619	652-671	753-765			
369	Zuver #19	" " "	1655	628-		695-715	-765	846-856			955
370	Lamb #6	" " "	1600			626-643					707
371	Keeley #9	Leyendecker	1464			455-496	509-533	609-620	655-667		720
372	Spence #7	" "	1622	531-546		620-645	683-698	778-790	830-840		900
373	Griffin #4	Sam Meels et al	1544	473-484		565-573	614-626	700-716			747
374	" #14	" " "	1613						816-832		857
375	Huidekoper #10	" " "	1713	640-		728-745	775-795	875-894			935
376	Noyes #17	So. Penn Oil Co.	1654	619-649		706-724	758-781	865-874	903-		961
377	Golden #19	" " "	1622	596-620		678-697	730-750	831-839	872-893		937
378	Carroll & Byers #7	W.E. Fertig	1614	615-651		700-719	752-772	856-863			973
379	Lytle #35	" "	1642	630-		727-739		875-883			896
380	" #44	" "	1657			759-776		915-929			
381	Loop #11-D	" "	1618	658-690		742-764					799
382	Huidekoper #G	Red Valley Oil Co.	1649	650-678		734-751	793-808	886-895	929-935		
383	McCaslin #4	W.E. Fertig	1494			581-602					621
384	S. Blanc #4	" "	1505			587-604	638-660	739-753	782-795		812
385	Morey #4	Fitts Bros.	1460	490-525		570-594	630-650	731-744	775-786		
386	Ceble #3-A	Red Valley Oil Co.	1568	564-599		654-681	700-735	814-831			833
387	Golden #21	So. Penn Oil Co.	1554	530-570		620-635	675-691	769-777			863
388	Byers #1	Clinger O & G. Co.	1522			545-560	597-618	603-703	739-756		821

389	Howarth #15	Bailey Bros.	1589			626-646		776-789	819-838		859
390	Dixon #12	" "	1506			523-544	-594	674-690	720-739		757
391	Stewart #10	" "	1567			583-610		741-753	785-810		836
392	Gordon #9-A	Pohickory Pet. Co.	1567	506-537		610-620		751-762	799-812		844
393	Wiley #22-A	" "	1670	613-635		704-718					766
394	Livengood #1	Livengood	1611	570-600		649-665	692-712	792-807	823-827		878
395	Cummings #3	Cummings	1637	582-616	642-645	667-690	722-741	820-823	865-898		913
396	Range #96 #1-A	Livengood	1581	527-560	583-597	618-647			824-841		
397	" 20-A #2	"	1494	450-485	505-515	542-568	591-612				628
400	Strawbridge #5	K.C. Buchanan	1466	500-543				751-764			797
401	Fulmer #14	A. Brecht	1417	435-460				683-698			730
402	Stuart #45	"D" Oil Co.	1582	590-615				863-900			925
403	Buxton #3-A	Pitt-Venango Oil Co.	1442	475-513				753-784			784
404	Buchanan #2	K.C. Buchanan	1615	666-722				914-931			961
405	Gehring #1	J.D. Trax	1477	529-568	568-573						620
406	Tract #1 well #6	Suger Creek Oil Co.	1513	540-595							612
407	Marsh #8-A	Pitt-Venango Oil Co.	1579	632-675				875-880	904-931		933
408	Stewart #33	" " "	1502	563-				799-805	832-853		880
409	Hamilton #3-A	" " "	1571	627-639					904-924		924
410	Benninghoff #5	Pitt-Venango Oil Co.	1476	546-570	613-624				824-842		871
411	Wiss #8	Bryner Bros.	1482	556-570					822-851		875
412	Landon #10	Success Oil Co.	1484	548-566	580-601				826-853		856
413	Benninghoff #30	" " "	1400	470-502	512-518		597-		744-769		790
414	" " #49	" " "	1417						780-815		862
415	Benninghoff #34	Success Oil Co.	1346						696-735		757
416	Terr #13	Bryner Bros.	1465						813-843		867
417	Espy #19	McCray & Espy	1355	425-470			571-595	674-678	709-729		769
418	J.S. McCray #7	J.S. McCray	1530	610-639			756-779		891-921		960
419	Rose #1	K.C. Breene	1480	565-605			724-750	834-839	867-		900
420	Hyde & Egbert #28	J.V. Frampton	1075	215-			324-349		455-491		535
421	Hayes #7	Straub	1079	180-220			318-341	431-435	464-496		567
422	Columbie #48	Brundred Oil Corp.	1472	568-610			713-735		845-882		938
423	" #35	" " "	1215	333-358			480-502	589-594	616-656		
424	Gage #15	Gage	1156				427-452		559-585		650

MAP NUMBER	NAME	OWNER	ELEV.	FIRST SAND	WHITE (Amber)	Red Valley (Lytle)	2nd.Sand (Salt)	3rd.Stray (Gray) (Black Oil)	3rd.Sand (4th.Sand) (Green Oil)	OTHER SANDS	TOTAL DEPTH
425	Meals #3	Ackerman	1573	663-702				913-915	945-956		980
426	Atkinson #15	"	1424	512-556	550-559			771-773	803-811		856
427	Ocean # 41	Brundred Oil Corp.	1365						735-775		837
428	Wilbert # 4-K	" "	1080				314-332		447-475		496
429	McNally # 38	" "	1509	607-662					880-829		980
430	Hess # 37	Brundred Oil Corp.	1442	566-604			704-712		839-868		887
431	Columbia # 92	" "	1318	428-450			567-590		700-742		803
432	(See deep well table)										
433	Peninsular	(from Carll)	(not fd.)	307-327				532-553			
434	Kerr well		"	270-310				508-520			
435	Hartman # 2		(not fd.)	487-528				717-731	758-795		
436	Dr.Siggins		"	179-227					530-546		
437	Buzard # 2		1427	454-474				715-725	752-764		

MAP NUMBER	NAME	OWNER	DATE DRILLED	ELEV.	CORRY SAND	FIRST SAND	RED VALLEY SAND	SECOND SAND	THIRD STRAY SAND	THIRD SAND
3	Early well	----------------------	ca 1800							
4	Grey well	----------------------	ca 1900							
5	Post well	----------------------								
6	Peul well	W.G.Rooder	1936	1644	175-210	419-485			670-672	718-720
14	Morrie well	(Reported drilled to the Queen Sand. No record available)								
50	Foeter #11	Bayliss,Blose & Wege	1923	1609					738-756	763-771
51	CWX	Petroleum Reclamation Co.	1939	1605		460-492			677-682	706-711
52A	Reported drilled to Queen Sand. No record available.									
57	Mersh #5	Summerton & Sutton	1930	1690	No Record.					
58	Knupp #2	Dunham Oil Co.		1595		446-509			686-705	717-725
59	Queen Sand well	George Hummer	(Reported drilled to Queen Sand. No record available)							
132	Philadelphia #83	J.P.Eaton Corporation		1604					675-710	
133	Lofgren #2	V.Lofgren	1922	1680					654-681	695-71
135	Gregory #5	(Reported drilled to Queen Sand. No record available)								
268	Dodd & Oakes #8	Petereon & Johneon		1423		230-355	405-	450-465	556-592	
269	Shenk #30	Clinger Oil & Gas Co.		1343		244-300		406-422	511-543	
270	Proper	Leyendecker	1937	(Record incomplete and from memory.)						
271	Wileon	----------------	1926	1589				609-614		
272	--------------	D.N. Burrows	1915	(Map location is approximate)						
274	Weteon deep well	Jonathan Weteon	ca 1870	1290 JFC	(See Carll's III page 154)					
275	Selkirk well	Norton & Jackson	1929	1240		184-250			465-495	
276	Boughton well	------------------	(Reported to be deeper than 1000'. No record available)							
277	Westcott well	------------------	(Location approximate. Reported drilled to 1810'.)							
278	Shamburg well	------------------	ca 1900	(Reported drilled to 2000'.)						
281	Shamburg #2	Ashworth & McCrey	ca 1893	1564		662-744	799-825		906-907	
285	Zuver # 37	R.M. Davideon Estate					674-692	726-746	828-838	865-885
286	Hunter #4	Pohickory Petroleum Co.	1937	1722	415-438	655-681	744-763	789-816	890-906	939-952
287	Vanderlin	------------------------	ca 1896	(Location uncertain)					845-849	883-899
398	Field	Red Valley Oil Co.	1939	1479						804-
432	Gileon Farm	Werner-Caldwell	ca 1920	1331					485-500	517-575

RED ROCK	FIRST WARREN SAND	SECOND WARREN SAND	QUEEN SAND	SPEECHLEY SAND	OTHER SANDS	TOTAL DEPTH	RESULTS
720-1140	1140-1175	1190-1260			950- 1100-1140	1300	Show of gas Dry
	1214-1241		1445-1483		1772 (shells)	1800 1000	Dry Show of oil Dry below third sand
940-1200 740-810	1075-1100	1200- 1125-1163	1339-1434 1200-1375	1600-1640 1463-1485	1660-1670 690-740	1725 1475 1811	Show of gas at about 1400' Dry
650-1000	1006-1027	1076-1127	1175-1299 1469-1529	1735-1770		1302 1784 1400 3553	Dry
	1450-1480	1019-1056	1130-1185 1750-1790	1306-1391	556-564	2303 2013	
988-1186 901-	1334-1374 1403-1435 1265-1280	1446-1473 1503-1539 1345-1380	1557-1658 1622-1715 1470-1560	1866-1892 1818-1848 1665-1675 ? -1440	2240-2270	1720 1954 2414 1825 1440	Show of oil and gas 1597-1608 Show of oil 1503-1539 Dry Dry

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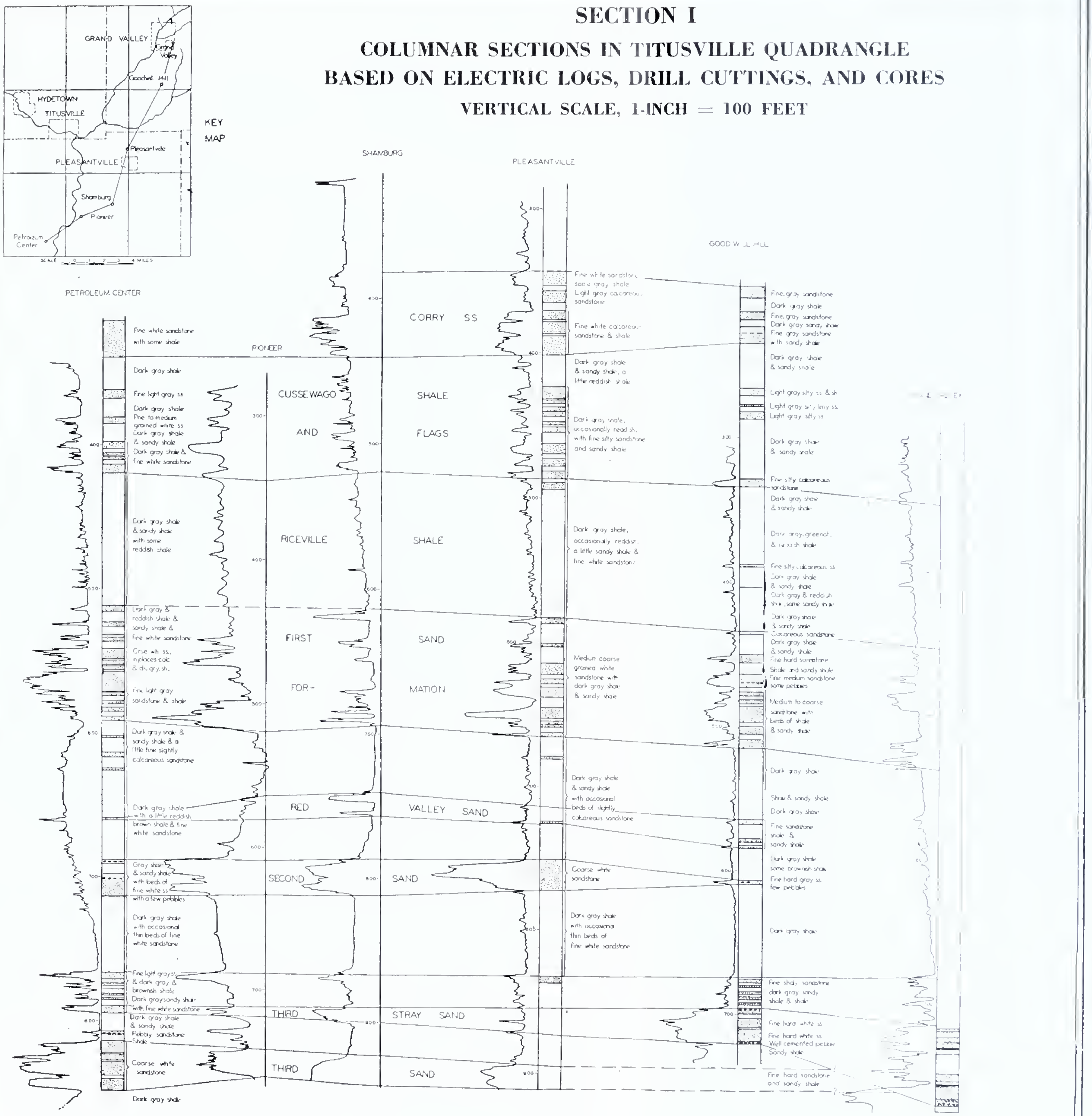
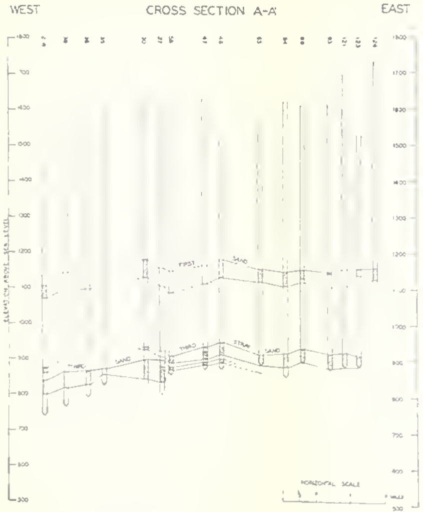
SECTION I

COLUMNAR SECTIONS IN TITUSVILLE QUADRANGLE BASED ON ELECTRIC LOGS, DRILL CUTTINGS, AND CORES

VERTICAL SCALE, 1-INCH = 100 FEET

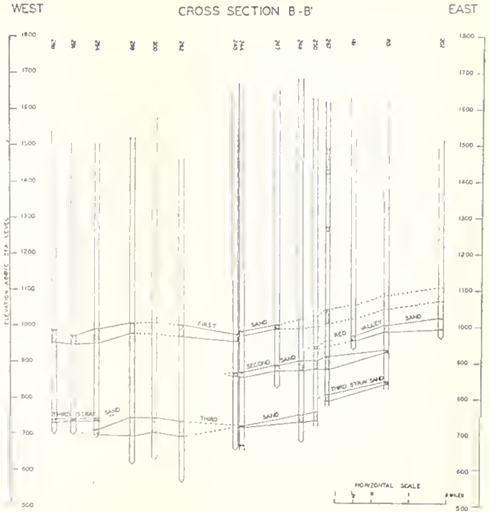

KEY MAP
GRAND VALLEY
Grand Valley
Goodwill Hill
HYDETOWN
TITUSVILLE
Pleasantville
PLEASANTVILLE
Shamburg
Pioneer
Petroleum Center
SCALE 1 0 1 2 3 4 MILES
PETROLEUM CENTER
PIONEER
SHAMBURG
PLEASANTVILLE
GOOD WILL HILL
GRAND VALLEY
CORRY SS
CUSSEWAGO AND SHALE AND FLAGS
RICEVILLE SHALE
FIRST SAND FORMATION
RED VALLEY SAND
SECOND SAND
THIRD STRAY SAND
THIRD SAND
Fine white sandstone with some shale
Dark gray shale
Fine light gray ss
Dark gray shale
Fine to medium grained white ss
Dark gray shale & sandy shale
Dark gray shale & fine white sandstone
Dark gray shale & sandy shale with some reddish shale
Dark gray & reddish shale & sandy shale & fine white sandstone
Crse wh ss, in places calc & dk. gry. sh.
Fine light gray sandstone & shale
Dark gray shale & sandy shale & a little fine slightly calcareous sandstone
Dark gray shale with a little reddish brown shale & fine white sandstone
Gray shale & sandy shale with beds of fine white ss with a few pebbles
Dark gray shale with occasional thin beds of fine white sandstone
Fine light gray ss & dark gray & brownish shale
Dark gray sandy shale with fine white sandstone
Dark gray shale & sandy shale
Pebbly sandstone
Shale
Coarse white sandstone
Dark gray shale
Fine white sandstone some gray shale
Light gray calcareous sandstone
Fine white calcareous sandstone & shale
Dark gray shale & sandy shale, a little reddish shale
Dark gray shale, occasionally reddish, with fine silty sandstone and sandy shale
Dark gray shale, occasionally reddish, a little sandy shale & fine white sandstone
Medium coarse grained white sandstone with dark gray shale & sandy shale
Dark gray shale & sandy shale with occasional beds of slightly calcareous sandstone
Coarse white sandstone
Dark gray shale with occasional thin beds of fine white sandstone
Fine, gray sandstone
Dark gray shale
Fine, gray sandstone
Dark gray sandy shale
Fine gray sandstone with sandy shale
Dark gray shale & sandy shale
Light gray silty ss & sh
Light gray silty limy ss
Light gray silty ss
Dark gray shale & sandy shale
Fine silty calcareous sandstone
Dark gray shale & sandy shale
Dark gray, greenish, & reddish shale
Fine silty calcareous ss
Dark gray shale & sandy shale
Dark gray & reddish shale, some sandy shale
Dark gray shale & sandy shale
Calcareous sandstone
Dark gray shale & sandy shale
Fine hard sandstone
Shale and sandy shale
Fine medium sandstone some pebbles
Medium to coarse sandstone with beds of shale & sandy shale
Dark gray shale
Shale & sandy shale
Dark gray shale
Fine sandstone shale & sandy shale
Dark gray shale some brownish shale
Fine hard gray ss few pebbles
Dark gray shale
Fine shaly sandstone dark gray sandy shale & shale
Fine hard white ss
Fine hard white ss
Well cemented pebble
Sandy shale
Fine hard sandstone and sandy shale
300
400
500
600
700
800

SECTION II



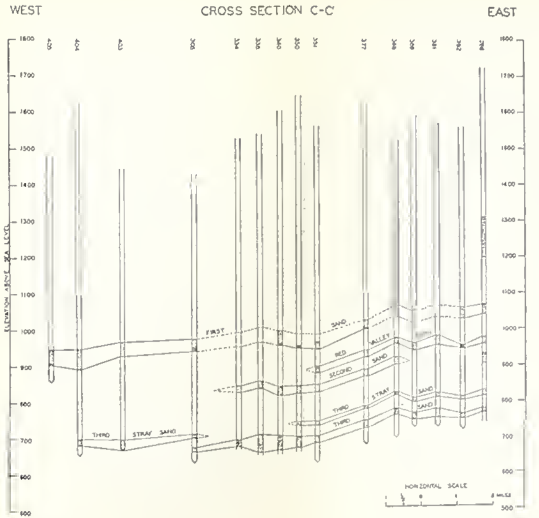
Section II. Well-to-well Section A-A', east-west, north.

SECTION III



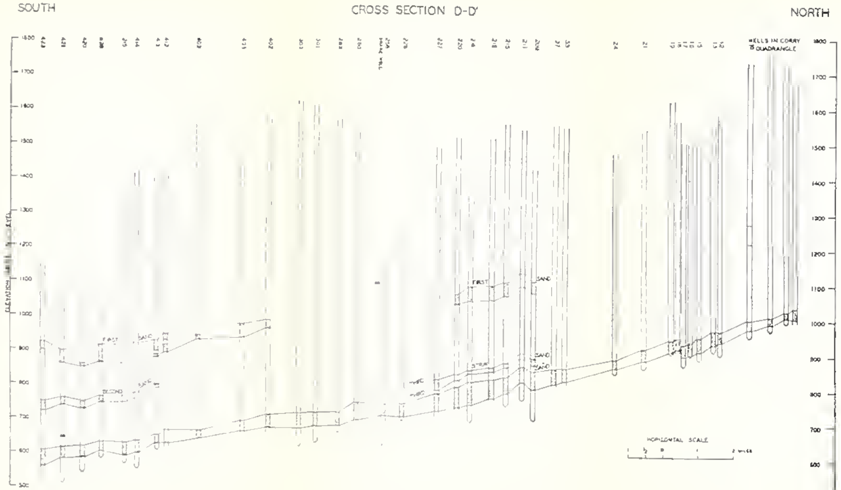
Section III. Well-to-well Section B-B', east-west, central.

SECTION IV



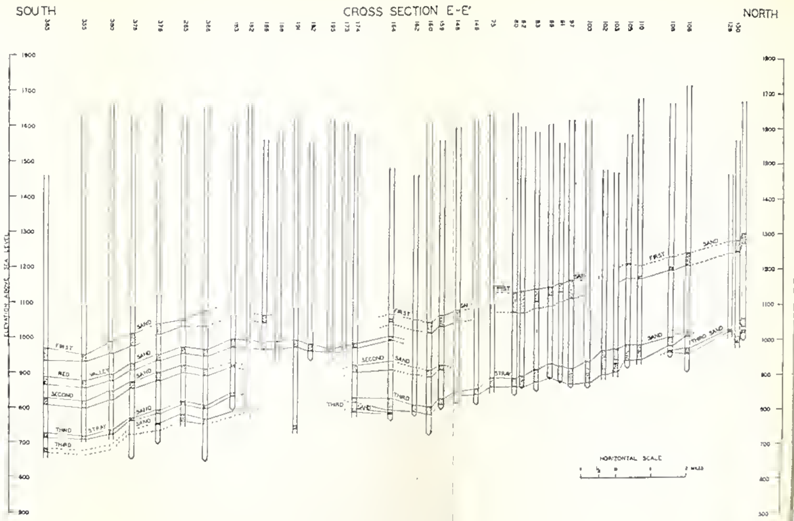
Section IV. Well-to-well Section C-C', east-west, south.

SECTION V



Section V. Well-to-well Section D-D', north-south, west.

SECTION VI



Section VI. Well-to-well Section E-E', north-south, east.

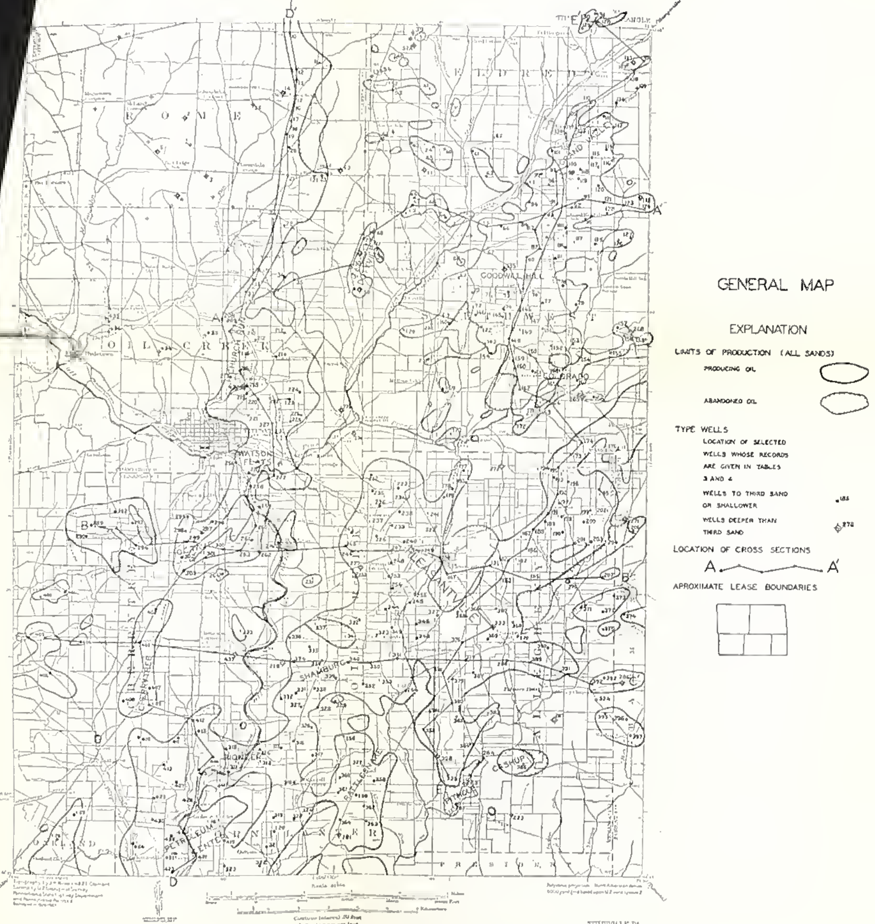

GENERAL MAP
EXPLANATION
LIMITS OF PRODUCTION (ALL SANDS)
PRODUCING OIL
ABANDONED OIL
TYPE WELLS
LOCATION OF SELECTED WELLS WHOSE RECORDS ARE GIVEN IN TABLES 3 AND 4
WELLS TO THIRD SAND OR SHALLOWER
WELLS DEEPER THAN THIRD SAND
LOCATION OF CROSS SECTIONS
A A'
APROXIMATE LEASE BOUNDARIES
ROME
OIL CREEK
GOODWILL HILL
COLORADO
WATSON FLATS
SHAMBURG
PLEASANTVILLE
PIONEER
PETROLEUM CENTER
PITHOLE
CASHUP
GRAND VALLEY
D D'
B B'
C C'
TITUSVILLE PA.

Plate 1. General map of Titusville Quadrangle showing location of selected wells, deep wells, approximate lease boundaries, and lines of cross sections.

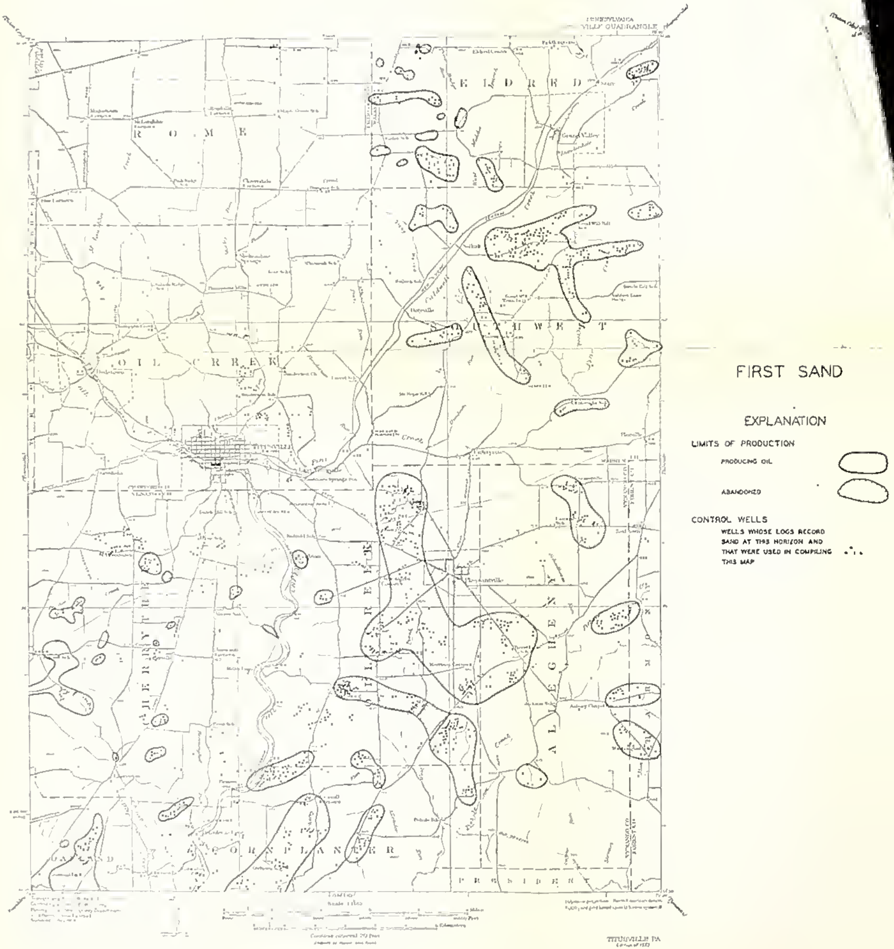


Plate 11. First Sand map showing location of First Sand pools, and wells which record the First sand at present.

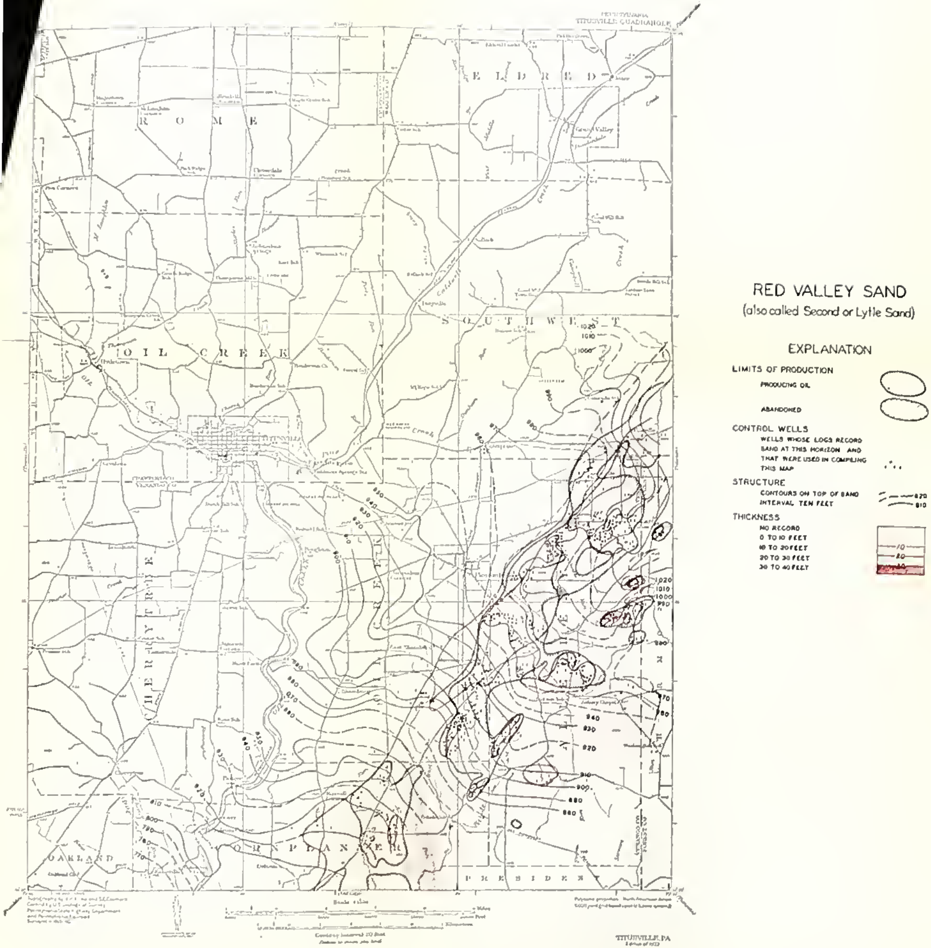


Plate III. Red Valley Sand map showing location of Red Valley Sand pools, Red Valley Sand wells, thickness of Red Valley sand (in red) and structure contours on top of Red Valley sand.

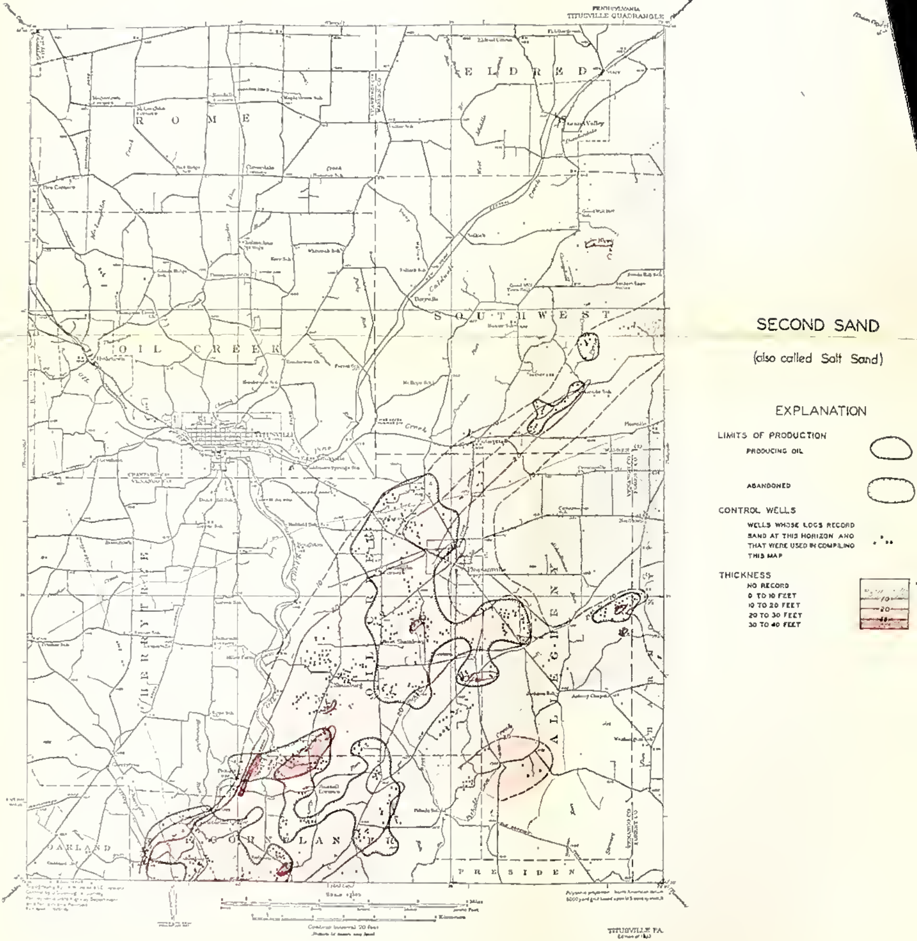
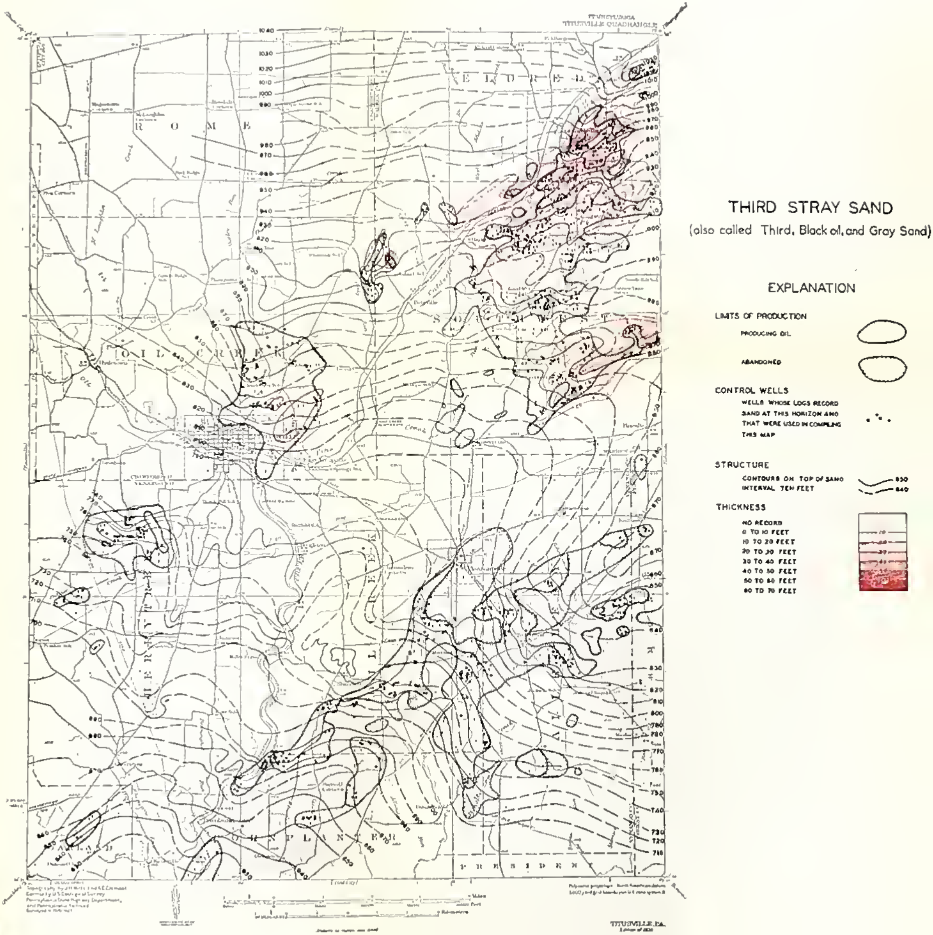


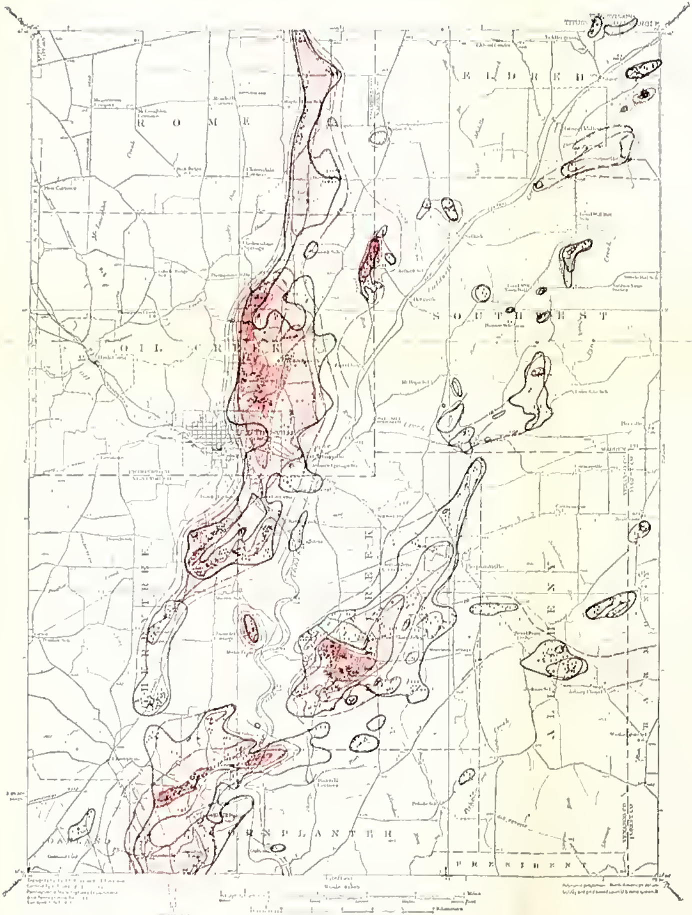
Plate IV. Second Sand map showing location of Second Sand pools, Second Sand wells, and thickness of Second Sand (in red).



THIRD STRAY SAND

(also called Third, Black oil, and Gray Sand)

Plate V. Third Stray Sand map showing location of Third Stray Sand pools, Third Stray Sand wells, thickness of sand (in red) and structure on top of sand.



THIRD SAND

(also called Green Oil or Fourth Sand)

EXPLANATION

LIMITS OF PRODUCTION

PRODUCING OIL

ABANDONED

CONTROL WELLS

WELLS WHOSE LOGS RECORD SAND AT THIS HORIZON AND THAT WERE USED IN COMPILING THIS MAP

THICKNESS

NO RECORD

0 TO 10 FEET

10 TO 20 FEET

20 TO 30 FEET

30 TO 40 FEET

40 TO 50 FEET

50 TO 60 FEET

OVER 60 FEET

Plate VI. Third Sand map showing location of Third Sand pools, Third Sand wells, and thickness of Third Sand (in red).

PAMPHLET BINDERS

This is No. 1527

also carried in stock in the following sizes

	HIGH		WIDE		THICKNESS			HIGH		WIDE		THICKNESS
1523	9	inches	7	inches	½ inch		1529	12	inches	10	inches	½ inch
1524	10	"	7	"	"		1530	12	"	9⅜	"	"
1525	9	"	6	"	"		1932	13	"	10	"	"
1526	9¾	"	7⅛	"	"		1933	14	"	11	"	"
1527	10½	"	7⅜	"	"		1934	16	"	12	"	"
1528	11	"	8	"	"							

Other sizes made to order.

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